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APPLYING THE
THEORY OF CONSTRAINTS
TO A BASE CIVIL ENGINEERING
OPERATIONS BRANCH

THESIS

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AFIT/GEM/DEV/91S-16

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APPLYING THE THEORY OF CONSTRAINTS TO A BASE CIVIL ENGINEERING OPERATIONS BRANCH

THESIS

Presented to the Faculty of the School of Systems and
Logistics of the Air Force Institute of Technclogy
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Table of Contents

Page

Acknowledgements ii

List of Figures vi

List of Tables viii

Abstract ix

I. The Challenges Facing Civil Engineering 1

Purpose of Civil Engineering 1
The Problem in the Operations Branch 3
Possible Solution 4
Research Objective 5

II. The Civil Engineering Work Control System 6

Work Order/Job Order Program 6
Scheduling Environment 9

III. An Introduction to Theory of Constraints Concepts 11

Definitions 11
Process 12
System 12
Dependent process 12
Constraint 12
Throughput 12
Inventory 12
Operating Expense 12
The Paradigm 12
The Goal 13
Performance Measurements 14
Throughput 14
Inventory 15
Operating Expense 15
The Constraint 15
Statistical Fluctuation and Dependent Resources 17
Ongoing Improvement 20
The Five Steps 20
Step 1. Identify the System's Constraint 21
Step 2. Exploit the System's Constraint 21

Page

	Step 3. Subordinate Everything Else to the Above Decision	21
	Step 4. Elevate the System's Constraint	22
	Step 5. If in the Previous Steps a Constraint has been Broken, go back to Step 1. Do Not Allow Inertia to Cause a System Constraint	22
	The Process of Change	23
	What to Change	23
	What to Change to	23
	How to Effect the Change	23
IV.	What To Change	25
	Defining a Goal for the Operations Branch . .	25
	Effect-Cause-Effect	28
	The Problem	30
	Detrimental Loop #1	32
	Detrimental Loop #2	35
	Detrimental Loop #3	35
	The Core Problem	37
V.	What To Change To	39
	The Evaporating Cloud Method	39
	The Operations Branch Evaporating Cloud . . .	40
	Assumptions	42
	Attacking the Assumptions	44
	Exposed	50
	Performance Measurements	51
	Throughput--Defining a Unit of Service . .	51
	Operations	52
	Recurring Work Program	53
	Job Orders	54
	Work Orders	56
	Units of Measure	57
	Inventory	57
	Operating Expense	58
	Performance Measurement Relationships	58
	The Five Steps of Focusing	60
	Identifying the Constraint in a Simple System	60
	Identifying the Constraint in the Operations Branch	62
	The Work Order Program as a Line System	65
	An Operations Branch Shop as the Constraint	70
	Establish a Constraint Shop	72

Page

Exploit the System's Constraint 73
Subordinate Non-constraints 73
Elevate the Constraint 74
Be Careful of Inertia 74

VI. How To Effect The Change 76

Past Management Policies 76
The Socratic Approach 77
Implementation 78

VII. Conclusions 82

Summary of Research Effort. 82
Findings 83
Conclusions 84
Recommended Future Research 85

Appendix A: Effect-Cause-Effect Diagram 86

Appendix B: Accumulated Work Order Hour Program 87

Bibliography 91

Vita 93

List of Figures

Figure		Page
1.	Typical Work Order Processing	7
2.	Typical Job Order Processing	8
3.	Typical Simplified In-Service Work Plan for a Shop	10
4.	A Chain	16
5.	Simple Two Process System	18
6.	Effect-Cause-Effect Diagram	29
7.	Decreasing Customer Satisfaction	31
8.	Long Work Order/Job Order Lead Times	32
9.	Graph of WP AFB Accumulated Work Order Hours	33
10.	Effects of Deteriorating Facilities	34
11.	Effect-Cause-Effect Loop #1	35
12.	Effect-Cause-Effect Loop #2	36
13.	Effect-Cause-Effect Loop #3	37
14.	Format of an Evaporating Cloud	40
15.	Statement of the Problem	42
16.	Efficiency Example	47
17.	Operations' Contribution to the Goal	53
18.	RWP Contribution to the Goal	54
19.	Completed JO's Contribution to the Goal	55
20.	Uncompleted JO's Contribution to the Goal	56
21.	WO's Contribution to the Goal	57
22.	Example of a Line System	61

Figure | Page

23. Process Times 62

24. A Line System with Backlogs 62

25. Work Order System 65

26. Graph of Backlog WO Hours to Actual Direct . . . 71

27. Performance Curves 79

List of Tables

Table Page

1. Production Capacities of a Simple System 19

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Abstract

The purpose of this thesis is to introduce the Civil Engineering manager to the Theory of Constraints management philosophy and to show how to apply this process of ongoing improvement to the Operations Branch.

One of the reasons for the success of Theory of Constraints in commercial firms is that it provides all levels of management the ability to find simple solutions for bridging the gap between local and global issues. This 'bridge' is built by clearly defining the goal of the organization and using performance measurements capable of predicting the effect of local decisions and actions on the goal.

Using the mission statement from Civil Engineering Doctrine and policy statements from The Civil Engineer, a goal is hypothesized for the daily peacetime efforts of a base level Base Civil Engineering Operations Branch. The goal is stated in such a way as to make measurement towards the goal possible. Performance measurements are postulated using the four services provided to base organizations: operations (utilities), job orders, recurring maintenance of base facilities, and work orders.

This thesis also shows that by managing all shops to their maximum efficiency, the maximum potential output of the organization cannot be realized.

APPLYING THE THEORY OF CONSTRAINTS

TO A

BASE CIVIL ENGINEERING OPERATIONS BRANCH

I. The Challenges Facing Civil Engineering

Purpose of Civil Engineering

The peacetime purpose of Air Force Civil Engineering managers is embodied in their mission statement:

> Prepare, sustain, and recover bases as platforms for the projection of aerospace power across the operational continuum. (1:7)

Since the mission statement is designed to encompass all Civil Engineering (CE) taskings under a multitude of scenarios, further analysis is needed to determine the day-to-day purpose of base level CE managers. The statement can be broken down into two scenarios: wartime and peacetime.

The wartime mission includes preparing a base for attack, sustaining during wartime operations, and recovering a base after attack. The preparation of bases in wartime consists mainly of constructing temporary facilities for personnel living and working on the base. The temporary facilities are normally replaced with more permanent facilities as time permits. Sustaining a base consists of those operations and maintenance actions required by the facilities. The recovery part of the mission plays a major part in continuing base operations after an enemy attack.

These taskings in a peacetime environment are similar. Preparing a base in peacetime is more a function of congressional approval and funding than the actual construction of the facilities. Peacetime recovery activities are normally limited to training exercises and natural disaster relief projects. The tasking of sustaining a base however, is very much the same as the wartime mission. Modifications to facilities are required periodically to meet the changing requirements of the base mission and mission support organizations and existing facilities still require periodic maintenance and repair.

When analyzing the CE mission statement, it is unlikely that "preparing" or "recovering" bases will have much to do with daily peacetime operations. Major preparations for a new base are approved and appropriated by Congress, well separated from the daily operations of most base level CE managers. Though recovering bases during peacetime may be required due to a natural disaster, it is not a daily concern of a base level CE manager. The purpose of daily peacetime operations therefore, focuses primarily on "sustaining" bases. The scope of which includes responsibility for operating utility plants; maintaining and repairing utility distribution systems, pavements, and structures; providing new construction; and meeting the changing requirements of base organizations.

There are other tasks required to sustain bases for continued operations in addition to those required to maintain the status quo. Base organizations periodically require facility and utility upgrades due to technological advances and must be supported by CE in order to sustain the bases' mission support requirements. This perpetual change of requirements combined with the mission statement of CE provides a more specific purpose for daily CE operations--to continually sustain base organizations and their changing requirements. These requirements include the daily needs of electricity, transportation, and work place necessities.

The Problem in the Operations Branch

The Operations Branch in most CE organizations generally has a large backlog of work orders (WO) and job orders (JO). Programs such as the Self Help program and the Simplified Acquisition of Base Engineering Resources (SABER) attest to the fact that CE is experiencing difficulty in accomplishing its mission at the rate it is being identified. Though it seems apparent there is a lack of resources to accomplish the present amount of work, resources are being cut further to reduce CE operating expenses.

On 4 February 91, Secretary of the Air Force Donald B. Rice announced management and personnel cuts throughout the Air Force. BCE organizations will lose 6,000 "predominately military" positions "by reducing management layers, reorienting base civil engineering squadron [sic] towards product/task accomplishment and concentrating military personnel in commands with wartime requirements" (2:7). In spite of the DOD's decreasing annual budgets and imminent manning reductions, the Air Force CE community is expected to continue to "maintain and operate an aging infrastructure" (3:1). Justifiably, CE is concerned about how it will maintain the current level of mission support with less money and manpower. One way to meet this challenge is to increase the productivity of CE's remaining work force.

Traditional methods of increasing productivity are normally related to an expenditure of money (e.g. purchase of computers or equipment). Additional money will be in short supply so future productivity increases will require innovative and inexpensive non-traditional methods.

Possible Solution

A recent nontraditional management philosophy gaining popularity because of its success among a number of leading commercial firms (4:15) is the Theory of Constraints (TOC). This new management philosophy provides a systematic approach to finding the key operation within an organization on which to apply Total Quality Management efforts. This operation is the bottleneck of the organization, or the constraint. The concept of a constraint is defined as "anything that limits the system from achieving higher performance versus its goal" (5:9). The TOC, formulated by Dr. Eliyahu M. Goldratt, maintains that a small number of constraints govern the performance of an organization and that relieving these constraints will improve the overall performance of the organization (6:146).

One of the reasons for the success of TOC is that it provides all levels of management the ability to provide effective, simple solutions "capable of bridging the gap between a local action and its global impact" (7:14-15). This bridge is built by clearly defining the goal of the organization and using performance measurements capable of predicting the effect of local decisions on the goal.

Research Objective

The purpose of this research is to define the concepts and techniques of TOC in CE terminology and processes in order to show the applicability of using this new management philosophy within the CE Operations Branch. This thesis applies TOC to a generic Operations Branch and leads the reader through the logic of managing the organization using TOC. It also shows how, by managing all shops to their maximum efficiency, the maximum potential output of the organization cannot be realized.

Though TOC can be applied to the BCE organization as a whole, or at the other extreme, a shop or job center individually, this research work focuses on the daily peacetime mission of the Operations Branch.

II. The Civil Engineering Work Control System

The information in this chapter is a review of the work order (WO) and job order (JO) programs, the processes involved in each program, the tasks required in each process before the WO/JO can move on to the next process, and the scheduling environment. Though most Civil Engineering (CE) personnel are familiar with this information, it is provided for those who may not be familiar with the work programs in CE Operations.

Work Order/Job Order Program

The Customer Service Unit is the single point within CE to receive, review, process, and control the flow of requests for work (8:15). Work requests are processed as a WO if detailed planning, real property capitalization, or reimbursement collection is required. Most other requests are processed by the simplified procedures of a JO. Though the specific processing of work may vary from base to base, the general principles are the same and are described in more detail below.

If the customers' request is classified as a WO, it follows the sequencing depicted in Figure 1. The Planning Section provides a rough estimate of total manhours and dollars required to complete the work. After the WO is approved, it is held in the Production Control Center until adequate manhours for involved shops are available. The WO then goes back to the Planning Section for detailed planning and creation of a Bill of Materials. Once the WO is planned, it is sent back to the Production Control Center and held until money is available to fully fund the Bill of Materials. Next, the WO is sent to Material Control for ordering of materials. Once all materials are received in Material Control, the WO is sent to Scheduling for inclusion in the monthly and weekly shop schedules. From this point to completion, the shops coordinate complementary actions in order to complete the work.

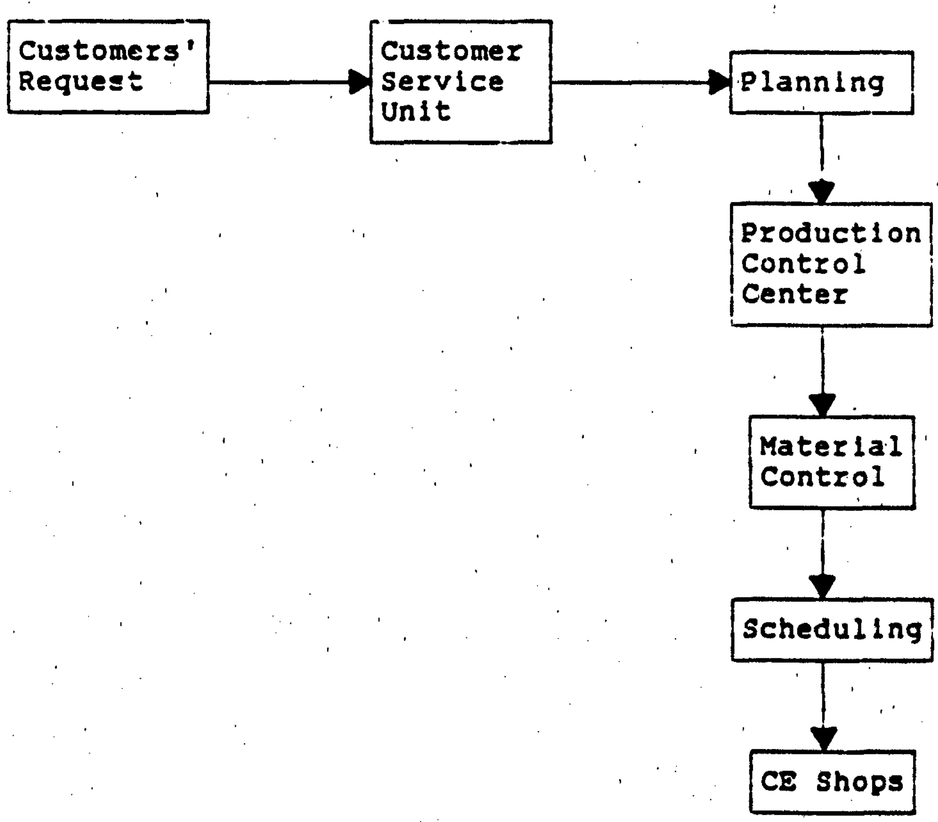

Figure 1. Typical Work Order Processing

Though JO processing is similar to that of WO's, it is simpler and normally quicker. Figure 2 illustrates a typical JO sequence. The Customer Service Unit initially determines if materials are available for a routine or urgent JO. If materials are available, or are not required, the JO is placed in a job hopper for weekly scheduling. If materials are required but not available, the JO is sent to

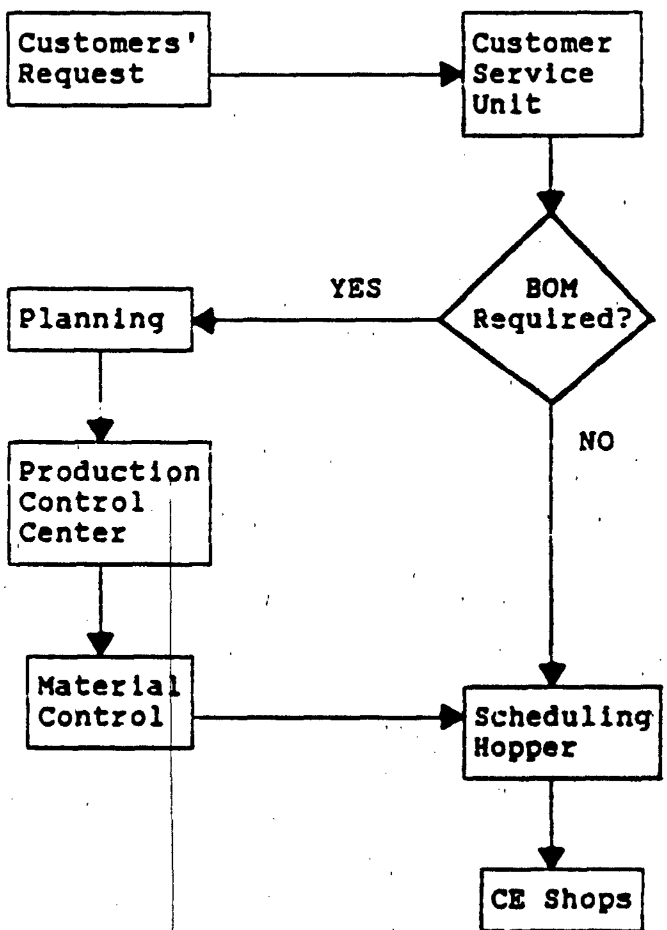

Figure 2. Typical Job Order Processing

Planning for a manhour estimate and a Bill of Materials. When the JO is planning complete the JO is sent to the Production Control Center and held until money is available for purchase of the materials. Material Control then receives the JO for material acquisition and returns it to the Customer Service Unit when the Bill of Materials is complete. The Customer Service Unit then places the material complete JO in the scheduling hopper for weekly scheduling. Emergency JO's are normally sent directly to the shop for immediate attention and materials are expedited by the shop.

Scheduling Environment

When preparing monthly schedules for the shops in the Operations Branch, the scheduler first establishes the total number of direct manhours expected to be available for each shop during the scheduling month. The expected number of manhours needed for emergency, urgent, and routine JO's is established from an average of actual manhours expended during past scheduling months. Recurring work program (RWP) manhours are determined by the Work Information Management System RWP program and the Prime BEEF office establishes the number of training manhours required for each shop. All the various manhour estimates are input into the in-service work plan (IWP) along with the estimated number of available direct manhours. See Figure 3.

WO's are scheduled only after the other requirements are met. The scheduler must balance the number of manhours

	Hours Scheduled	Hours Available	
Available Direct		6,261	
Emergency Job Orders	1,150	5,111	
Urgent Job Orders	2,049	3,062	
Routine Job Orders	1,496	1,566	
Recurring Work Program	135	1,431	
Prime BEEF	640	791	
Work Orders	791	---	(100% Scheduled)
- - - - - - -			
Work Orders	179	1,252	(80% Scheduled)

Figure 3. Typical Simplified In-Service Work Plan for a Shop

available, for material complete WO's to be scheduled in one shop, with manhours available in all other shops that are involved in that WO and ensure the manhours scheduled for each shop do not exceed the manhours available. The scheduler is evaluated on how efficiently the shops are scheduled. This puts pressure on the scheduler to schedule each shop for as many hours as possible and therefore has significant impact on shop efficiencies. For example, the scheduler wouldn't want to schedule a shop for only 80 percent of its available direct hours if a material complete WO was available for scheduling. They try to schedule all shops at 100 percent of available direct hours.

III. An Introduction to Theory of Constraints Concepts

Though the Theory of Constraints (TOC) literature is primarily directed at production-oriented businesses, the definitions and techniques used are general enough to apply to all types of organizations including non-profit, service organizations.

In Volume 1 of The Theory of Constraints Journal, Dr. Goldratt thoroughly explains how differences between a local department's objectives and global objectives of top management cause distortions in the information passed between them (9:9). TOC eliminates these distortions by focusing local decisions and actions so they can contribute positively to the global objective of the organization. The focus is provided by establishing the global objective and identifying the operation limiting the attainment of the objective--the goal and the organization's constraint.

This chapter defines TOC concepts and describes the thinking processes and techniques of the TOC paradigm.

Definitions

When trying to explain new ideas and concepts, a list of basic definitions is useful. It provides a common base from which to build upon and develop more complex concepts. The definitions listed below are basic to understanding the principles and thinking processes of TOC and most are further defined in later sections. The primary sources for the following definitions are The Goal--A Process of Ongoing Improvement and The Race (10, 6).

Process. In a production organization, there is a series of steps in the production sequence where something is performed on the product. Each individual step is considered a process.

System. A system is a series of processes. It can also be used synonymously with an organization where each department, or branch is a process.

Dependent process. A situation where one process cannot start work on a product until the preceding process has finished its work on that product.

Constraint. That process with the longest process time in a system where dependent processes exist.

Throughput. The rate at which the system generates money through sales.

Inventory. The money invested by the system in order to turn inputs into outputs.

Operating Expense. All the money the system spends to convert inventory into throughput.

The Paradigm

The paradigm inherent within TOC consists of principles, techniques, and thinking processes serving two purposes:

1. To convince an individual that intuition (experience dealing with the system) can identify the real

problem and provide a general solution to the system's problem.

2. To provoke and to focus the manager's ability to verbalize intuition into effective, practical procedures (11:79-81).

To understand the impact of this paradigm, the separate elements of TOC and the relationships between them need to be discussed in detail. The goal and measurement towards the goal need to be understood in terms of the performance measurements--throughput, inventory, and operating expense. In addition, the constraint should be viewed in terms of its effect on the organization, and the effect of statistical fluctuations on the constraint. Finally the process of ongoing improvement should be understood in terms of the five steps of improvement and the process of change.

<u>The Goal</u>. The first step of the paradigm is to define the system's goal. Since no organization was established just for the sake of existence, it must have a purpose--the goal (11:4). TOC places great importance on defining the system's goal because it is the cornerstone against which the effectiveness of every action or decision must be judged. In other words, if the result of a local decision does not improve the system's performance towards the goal it is a bad decision. Since the concern of management is improving performance, the requirement of defining the goal becomes obvious.

Performance Measurements. Performance measurements must be present to bridge the gap between a local decision's impact and the system's goal. It is not enough that measurements are available to judge the attainment of the goal after the decision is made, they must be able to direct decisions and actions towards attainment of the goal (5:13). For example, net profit is a good measure of an organization's performance towards the goal of making money. But how would a branch level manager know if the purchase of a new machine for the branch will increase the organizations net profit if the only source of information is last month's profit statement?

TOC proposes three measurements that meet the criteria of bridging the gap and directing decisions. They are throughput, inventory, and operating expense. These important terms are further defined below.

Throughput. The above definition applies to a for-profit organization where the goal is to make more money now and in the future. A more generic definition that applies to any organization is: the rate at which a system generates output relative to its goal.

A further refinement of the meaning of throughput explains why specific words are used in the definition. Since the definitions are meant to be generic in nature, 'system' is used to entail any kind of group from a multi-million dollar organization to a Boy Scout Troop. Any type of system, as long as it has a goal produces some type of output. The amount of output means very little unless a time frame is specified in which the output is generated. This 'output per time' relationship naturally leads to a rate of output. Whether a system's output is dollars per month or miles per hour, both can be considered a system's throughput.

Inventory. Anything a system purchases with the intent to sell sometime in the future is considered inventory. It is not limited to just materials but includes capital investments like machines and buildings.

Operating Expense. Money spent on turning inventory into throughput. Notice the use of the word 'spent' when defining operating expense versus 'invested' when defining inventory. Expenditures for operating expense include direct labor, salaries for secretaries and executives, depreciation, and any other expense required by the system to allow it to turn inventory into throughput.

The Constraint. When trying to understand the concept of a constraint, Dr. Goldratt uses the analogy of links in a chain to processes in a system. The strength of a chain is only as strong as the weakest link. Therefore, the analogous question is how strong, or productive is the system? To determine the answer you need to find the slowest or most overloaded process, the weakest link. This process is the constraint of the system. If the output of this process is improved, the output of the whole system will improve.

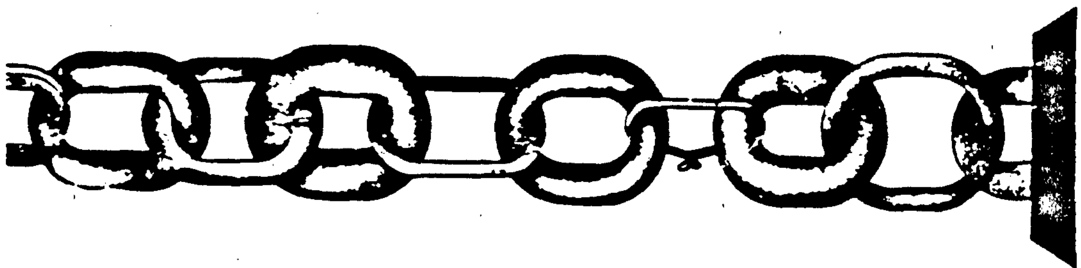

Figure 4. A Chain

A system constraint is further classified by 'where' or 'what' produces the constraint. A 'market constraint' is present when the system's output is limited only by the market's capability to absorb the system's output. In this case the constraint is outside of the system and throughput can be increased only by increasing the market share.

The worst possible constraint is the 'vendor constraint.' This is a case where an input material is constantly in short supply throughout the marketplace and the system cannot get enough of the material to supply the market potential. This is the worst type of constraint because the limiting factor of a systems output is not under the manager's control.

A 'resource constraint' occurs in a system when the productive capacity of the system is less than what the market can absorb. In this case the process limiting the system's productive capacity is a resource constraint.

The last type of constraint is the 'policy constraint.' This constraint is the easiest type to eliminate. A policy constraint is present when policy alone limits the amount of output from a system. Simply by changing the policy an immediate improvement in production, or increased output is witnessed.

Managers should focus on the constraint when trying to control a system's performance. The processing rate of the constraint controls the rate of output of the system. Does this mean that if the constraint is not producing, the system is not producing? According to Goldratt, the answer is yes. In addition, the cost of the constraint being idle for an hour is equal to the cost of every process in the system being idle for an hour (10:157-158).

Statistical Fluctuation and Dependent Resources. In order to understand why the concept of a constraint holds such a key role in the application of TOC, it is necessary to review the statistical concepts Goldratt refers to as statistical fluctuations and dependent resources (SFDR). Statistical fluctuations exist anytime the duration of an activity cannot be precisely determined. If an average is used in calculating a process time or establishing a schedule, it is subject to fluctuation. When a job is estimated to take four hours, it is not meant that it will take exactly four hours to complete the process. Job planning is accomplished by using estimates and may actually take three, or even six hours to accomplish the job.

Almost every process contains significant amounts of fluctuations which become more pronounced where 'dependent resources' exist. Dependent resources means that one process cannot start until the preceding one is complete. This situation exists in any organization where the completion of a task requires a sequence of more than one task or resource.

Statistical fluctuation and dependent resources are separate concepts that have a definite impact on an organization. However, it is their coexistence that creates problems for the manager.

The effects of SFDR are demonstrated in the following example (12). The simple system consists of two processes, in sequence where process B must follow process A. See Figure 5. Each process averages four units per day and the market requirement is four units per day. To keep the example simple, each process can only produce either three or five units per day with a 50/50 probability.

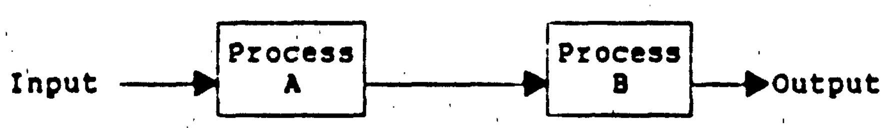

Figure 5. Simple Two Process System

Table 1 shows all possible combinations of production for the two dependent resources.

Table 1. Production Capacities of a Simple System

	Production Capacity Process A		Production Capacity Process B		Output
Day 1	3	→	3	→	3
Day 2	3	→	5	→	3
Day 3	5	→	3	→	3
Day 4	5	→	5	→	5
			Total Output		14

On Day 1 Process A produced 3 units and Process B produced 3 units. On Day 2 Process A produced 3 units and Process B could have produced 5 units but was provided with only 3 units so the days output was 3. On Day 3 Process A produced 5 units but Process B could only produce 3 units so again the days output was 3 units. On Day 4 Process A produced 5 units and Process B was also able to produce 5 units so the output of Day 4 was 5 units. Notice the average output for processes A and B is four units per day, as expected, but the total output for the four possible daily outputs is only 14. Therefore, the average number of units transferred to the market is only 3.5 units per day.

The description of the hike in <u>The Goal</u> is a more thorough explanation of the damaging impact of SFDR. In this example throughput is described as the rate at which the last hiker walks over the trail, inventory is the amount of trail between the first hiker and the last, and operating expense is the energy expended in walking the trail. This simple analogy shows that individual fluctuations of the process times do not average out when dependent resources are present. Rather it is an "accumulation of slowness--because dependency limits the opportunities for higher fluctuations" (10:96-101). The only way to achieve average is through carefully controlled improvements.

Ongoing Improvement. All living systems exist within a dynamic environment. Without the capability to adapt to changes within the environment, the system will become extinct. According to TOC, the way to ensure both growth and survival for U.S. manufacturing firms is to adopt a process of ongoing improvement. The importance of ongoing improvement in a changing environment is stated in The Race:

> The marketplace today is more crowded, faster-changing and more fiercely competitive than at any time in history....What was once relatively gradual change has in recent years turned into a race of exponentially increasing intensity. Those unable to continually improve are falling behind, since success in this environment requires more than a one-time improvement....something far greater than a few sporadic improvements is now needed. Indeed, the only way to secure and improve one's competitive position today is by instituting a process of ongoing improvement. (6:144)

The Five Steps. Up to this point, only the concepts used by TOC have been introduced. The framework a manager needs to direct the power of TOC's concepts is still lacking. This framework is embodied within "The Five Steps of Focusing" (11:3-6).

Step 1. Identify the System's Constraint. The definition of a constraint gives the manager clues as to how to identify it. Look for the things that are in short supply, or long processing times which impact the system to the point of limiting output. If more than one constraint is identified, prioritize them according to their impact on the goal. This ranking will help to eliminate needless effort on trivial problems.

Step 2. Exploit the System's Constraint. By definition, the constraint limits the throughput of the system. By exploiting the constraint, the manager ensures that the capacity of the constraint is not wasted. There are two ways to ensure the constraint's capacity is not wasted: 1) make sure that there is always input available for the constraint to work on. Remember, if the constraint has to wait for input, processing time is lost for the entire system. 2) make sure the constraint only works on inputs that need to be processed. If the constraint is processing work for future requirements at the expense of current work requirements, throughput is wasted and that wasted time is lost for the entire system.

Step 3. Subordinate Everything Else to the Above Decision. Subordination deals with how to manage the majority of the system's processes, the non-constraint processes. The focus of the five steps is verbalized in this step. Non-constraint resources should not produce more than the constraint can process. Producing more input for the constraint than it can process is wasted since the constraint cannot meet the production of the non-constraints. The implication for the manager is to not manage non-constraint resources tightly unless they start to interfere with the schedule of the constraint resource.

Step 4. Elevate the System's Constraint. Ask the question: How can I increase the output of the constraint? The answer may include schedule changes, investments, or policy changes. Though it is natural for a system to have a constraint, the location of the constraint is not an act of nature. Management can control the location of the constraint by modifying the capacity of the different processes in the system. There is always a way to increase the capacity of the constraint until the constraint is 'broken' (moves to a different process).

Step 5. If in the Previous Steps a Constraint has been Broken, go back to Step 1. Do Not Allow Inertia to Cause a System Constraint. Since the breaking of one constraint will not allow the system to produce an infinite amount of throughput, another process must become the constraint. What normally happens when a constraint is broken, is managers do not go back and review the formal and informal rules developed for managing the former system's constraint. These rules then become policy constraints on the new system.

The Process of Change. The five focusing steps provide a sequential process for applying TOC to the system. Though the five steps are powerful, they cannot ensure continuous improvement. Goldratt explains the difficulty of setting an organization on a process of ongoing improvement by verbalizing the "devastating process that connects improvements to emotional resistance:"

> Any improvement is a change.
> Leading to:
> Any change is a perceived threat to security.
> Leading to:
> Any threat on security gives rise to emotional resistance.
> Leading to:
> Emotional resistance can only be overcome by a stronger emotion. (11:10-11)

Because of this resistance to change, Goldratt introduces an ordered approach for dealing with the process of change (11:7-8). Determine first what needs to be changed, second what to change to, and third how to effect the change.

What to Change? Management should determine the core problem; the problem that will have a major impact on the organization.

What to Change to? The manager needs to develop a simple, practical solution. TOC maintains that complicated solutions have a small chance of working.

How to Effect the Change? Management needs to break the connection between 'improvements' and 'emotional resistance.' This part is the most difficult. To solve this dilemma, answer the following question: Who is the only individual not likely to be threatened by a change? Of course it is the person that suggests the change. This "emotion of the inventor" (11:15), Goldratt suggests, is stronger than the resistance to change.

The next three chapters describe this process of change in terms of the Civil Engineering Operations Branch.

IV. What To Change

This chapter applies the basic definitions, concepts, and processes introduced in Chapter III to the Civil Engineering (CE) Operations Branch. Realizing that only the owner of an organization can establish the goal, this chapter derives a generic goal for the Operations Branch from current mission statements and Air Force Civil Engineering policy.

In this chapter a technique called Effect-Cause-Effect is used to help the manager determine what is holding the organization back from attaining more progress towards the established goal. Verbalizing the cause and effect relationships, logically derived from the current situation, starts the Process of Change.

Defining a Goal for the Operations Branch

Senior CE managers are stressing the importance of providing quality facilities (3:1). In addition to quality facilities, CE must provide the right quantity of facilities at the appropriate time (13). A facility, whether utility, pavement, or building, must meet minimum quality standards. It is of little use to the user if the quality is so poor that it does not meet the minimum requirements. Quantity is also vital to customers. If the proper quantity of facilities is not provided, the customers' mission capability is degraded. Finally, a customer cannot perform the mission unless the facility is provided when it is needed. These three concepts; quality, quantity, and timeliness, are at the basis of any customer oriented service organization.

Can the goal be stated in terms of quality, quantity, and timeliness? The problem with the goal stated in these terms is that there is currently no way to measure performance towards this goal. Measurement is critical and can be complicated. Three separate measures would be required, one each for quality, quantity, and timeliness.

Major William Duncan's PhD dissertation, when complete, will calculate an annual condition index for each building. This index will provide a quantifiable indication of the overall quality of facilities provided to base customers (14:14). One way to measure the quantity and timeliness of facilities is for customers to provide CE with a rating of their satisfaction through a customer questionnaire.

The major flaw with these measurements is the inability to provide a way to <u>direct</u> decisions regarding use of manhours and budgeted dollars. It is more important to direct or guide effective decisions relative to future impacts on throughput than to judge the effectiveness of a decision already implemented. It appears, therefore, that a goal stated in terms of its requirements does not lend itself to the development of suitable performance measurements.

Maybe a different approach to defining the goal will clarify this issue. Ask the question: How does a for-profit, service organization measure progress towards its goal of making more money now and in the future? It measures profit. The next question is: How is a company's profit related to the customer's needs of timely, quality service of the right quantity?

The answer to this question is given by answering three more questions:

1) Will a company continue to make a profit in the future if the service it provides does not meet quality standards?

2) If the company is repeatedly unable to provide a sufficient quantity of services to meet the customer's needs, will it continue to make a profit?

3) If the service is continually provided after the customer needs the work completed, will the company continue to attract customers and make a profit in the future?

The answer to all three questions is, of course: No.

Customers do not normally return to a company for more work if they were not satisfied with the quality, quantity, and timeliness of past work provided by the service organization. So it seems that satisfying customers should be the goal and quality service in the right quantity and when requested by the customer are requirements that must be met before achievement of the goal is possible. This is nothing new. Upper level CE management have been stressing customer service for a number of years (8:7). The new point here is the verbalization of the requirements for providing that customer service.

A for-profit organization measures its ability to maintain customer satisfaction by measuring profit. However, as a military organization, it is difficult to state 'the goal of CE is to make a profit.'

A hypothesized goal for CE, incorporating the idea of continued customer service through quality facilities, in the right quantity at the time they are needed is as follows: "To produce more 'units of service' (some measurable quantity) now and in the future."

Effect-Cause-Effect

This technique provides the manager a way to use the logic inherent in a situation to validate cause-effect relationships (11:22). Used in this way a manager can speculate a cause (Cause #1) for a given effect (Effect #1) and validate the relationship by predicting other effects (Validation Effect #1) stemming from the same cause. See Figure 6. After Cause #1 is sufficiently verified, the manager can view it as an effect and logically determine its cause (Cause #2) providing other effects of the new cause to validate (Validation Effect #2) the original cause-cause relationship. Working in this way the manager builds a "logical tree" capable of explaining numerous cause-effect relationships. Eventually the tree will lead the manager to the root problem from which all the other causes originate (5:34).[1]

At times a detrimental loop is uncovered in the effect-cause-effect analysis. This loop is present when an effect becomes a cause for another effect that eventually becomes a cause for the original effect (Effect #1 causes Cause #2). The loop then signals the presence of a "death spiral" in the organization unless the loop is broken.

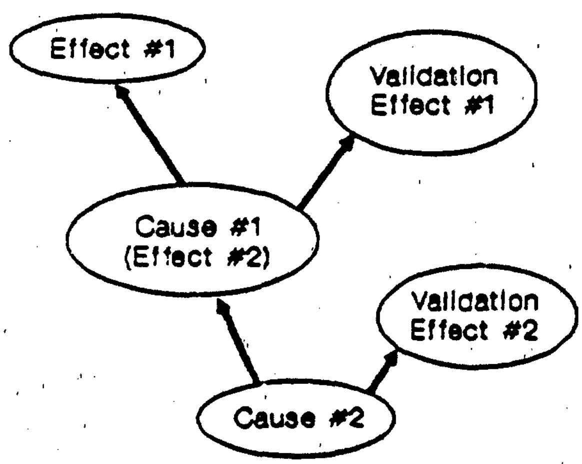

Figure 6. Effect-Cause-Effect Diagram

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1. This short explanation of the effect-cause-effect technique is intended to help the reader follow the reasoning of the following section. A more in-depth explanation of this technique is found on pages 22-35 of Dr. Goldratt's book titled <u>What is This Thing Called Theory of Constraints and How Should it be Implemented</u>.

The Problem

In general, customer satisfaction with CE performance is low. This can be verified by the fact that CE organizations are being forced to convert to a zonal maintenance type of organization because senior CE management believes this new organization will increase performance. One to two year lead times for work order (WO) completion, job orders (JO) that take over 30 days to complete, and CE's apparent inability to control indoor heating, ventilating, and air conditioning systems are items that lead to poor customer satisfaction.

As mentioned, one of the main causes for decreasing customer satisfaction is the long lead time for getting a WO accomplished. This applies not only to work requested by the customer, but also requirements identified in facility surveys which are lumped into large contract projects. Projects for upgrading utilities within facilities are not very high on the priority list and therefore may never get accomplished, which further increases RWP costs and the number of JO calls on the system. Creation of the Simplified Acquisition of Base Engineering Resources (SABER) program validates the statement that WO and JO lead times are getting longer. The SABER was originally created as a way to provide a quick response capability without taking CE personnel away from RWP and emergency and urgent JO's. See Figure 7.

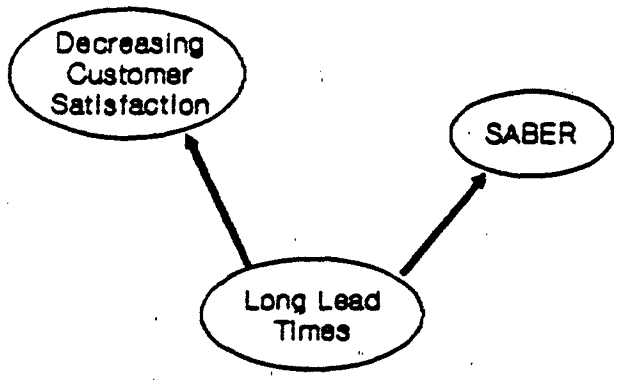

Figure 7. Decreasing Customer Satisfaction

Long WO and JO lead times exist because of the large number of WO/JO's awaiting accomplishment. There are WO's and JO's awaiting attention at almost every process in the WO/JO system. A large number of WO's are awaiting approval, a large number of WO's are awaiting planning, a large number of WO's are awaiting funds, a large number of WO's are awaiting materials, a large number of WO's are awaiting scheduling, and the same can be said of the number of JO's awaiting either materials or completion. See Figure 8. What is the reason for this large number of WO/JO's? One reason is that many bases, not slated for closure, are receiving missions transferred from bases scheduled to close. When this happens new facilities are often needed to house the newly acquired mission. Many bases are forced to renovate old facilities no longer used because there was not enough money for new facilities.

What does this do to the number of WO/JO's pumped into the system? It greatly increases the amount of work being pushed into CE and further increases the long lead times created by the already large amount of accumulated work.

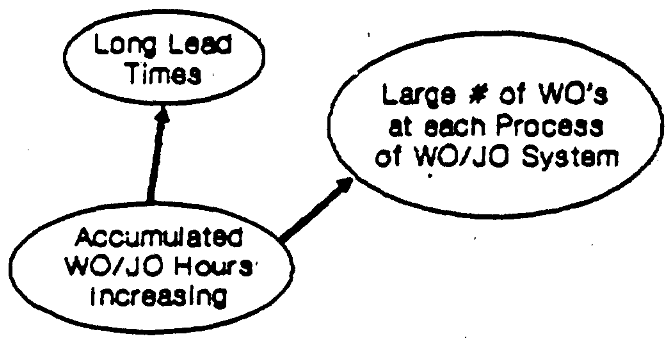

Figure 8. Long Work Order/Job Order Lead Times

Further validation of the increasing workload of CE is provided in Figure 9. This graph totals the number of manhours for all planned but unaccomplished WO's at the end of each month at Wright-Patterson AFB.

Detrimental Loop #1. It is not difficult to figure out that aging facilities increase the work load of personnel assigned to facility maintenance. This aging causes all facilities on a base to deteriorate at various rates which increases the work load of CE and further increases the already long lead times of WO/JO's. See Figure 10.

The facility aging process is further aggravated by the lack of proper RWP being performed (15:2-3) on most bases and

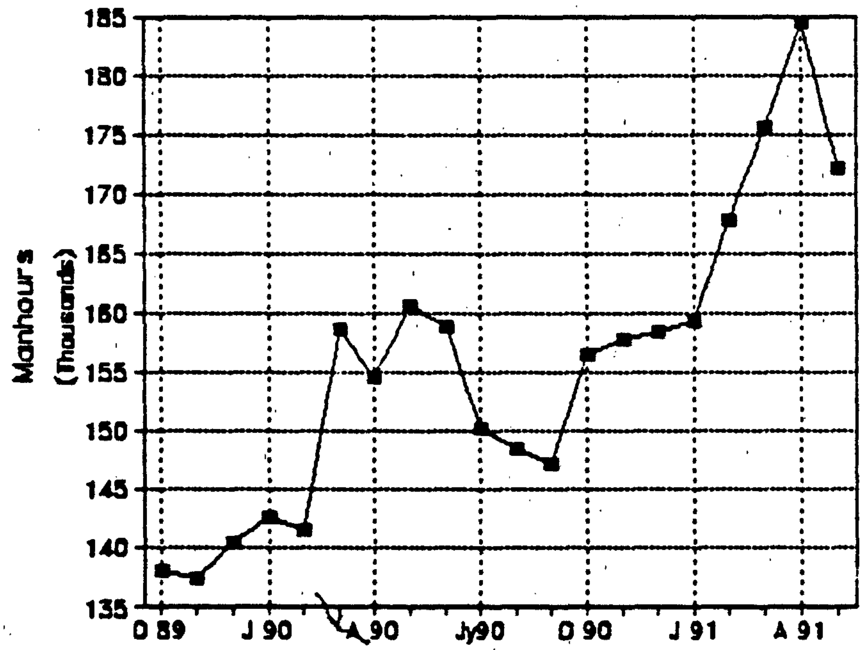

Figure 9. Graph of WP AFB Accumulated Work Order Hours

the lack of in-house projects developed from facility surveys. This is partly due to the pressures for the shops to accomplish more work than they have direct hours available. This puts great pressure on shop personnel to 'pencil whip' the RWP actions. Much of this pressure is due to the amount of work scheduled for the shop at the weekly and monthly scheduling meetings. The performance of the scheduler is measured on how well they schedule the shops to attain the highest shop availability rates possible. This pressure, together with the fact that the WO/JO estimates are only estimates, and subject to statistical fluctuations, cause the scheduler to overload shop schedules. This overloaded schedule puts pressure on the shop foremen to push their personnel to accomplish the scheduled work. In many cases, the only way for shops to accomplish all of the scheduled work, is to pencil whip some of the requirements that are not likely to be noticed. The amount of RWP actually performed only on paper, eventually takes its toll on the shop workload by increasing the number of JO's (15:12). See Figure 10.

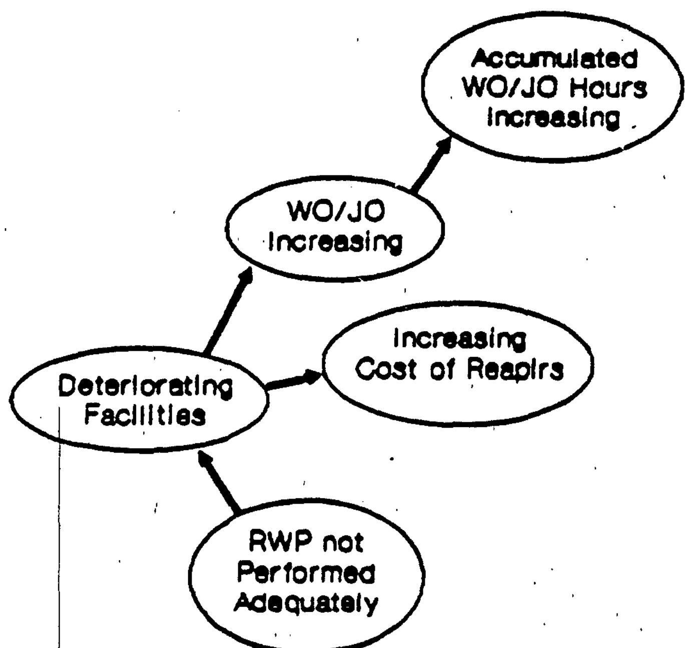

Figure 10. Effects of Deteriorating Facilities

To summarize this death spiral, the backlog of in-service work (IWP) increases because of the increasing accumulated WO/JO hours caused by the deteriorating facilities caused by over-scheduling IWP caused by the increasing accumulated WO/JO hours, etc. which leads to detrimental loop #1 depicted in Figure 11.

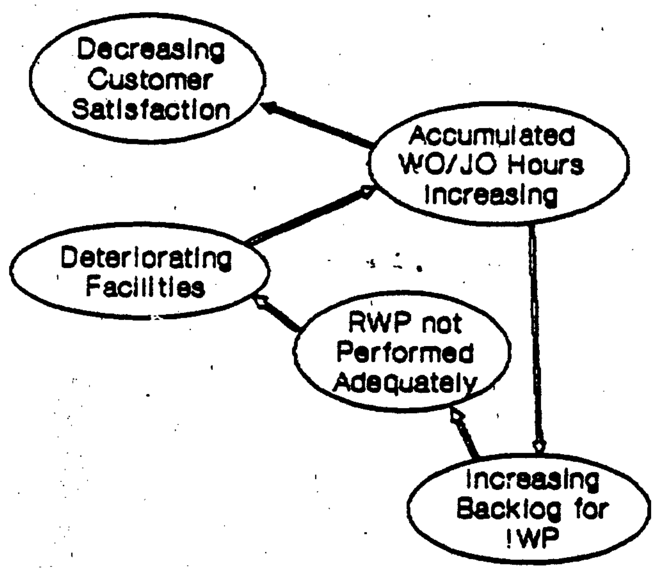

Figure 11. Effect-Cause-Effect Loop #1

Detrimental Loop #2. Deteriorating facilities increases the amount of work required on each facility to maintain it in a usable condition. The increased work required tends to increase overall repair costs of the facility which causes a further shortage of funds causing an increase in the number of WO's held for funds causing an increase in the IWP backlog, etc. This sequence of effects leads to detrimental loop #2 depicted in Figure 12.

Detrimental Loop #3. Continued deterioration of facilities also causes another effect. Deteriorated facilities cause command interest projects to surface.

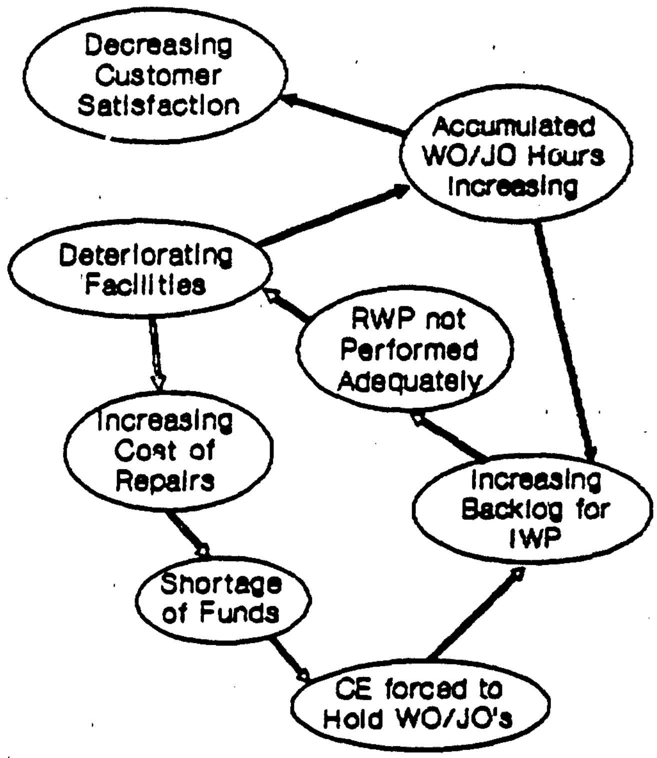

Figure 12. Effect-Cause-Effect Loop #2

These are special projects that would not get accomplished in the desired timeframe if the WO was allowed to process normally through the large CE accumulated backlog. The introduction of special interest work into the schedule further delays other work. This practice of insertion is expensive because the diverted resources and expenditure of funds, already in short supply, causes a further drain on the money supply. This shortage of money causes a further backlog in the IWP, the insertion also absorbs manpower and money slated for another WO/JO or RWP action that now must be delayed. This delay of completion of the RWP is now late or pencil whipped which causes a further deterioration of facilities causing another special interest insertion, etc. causing detrimental loop #3 depicted in Figure 13.

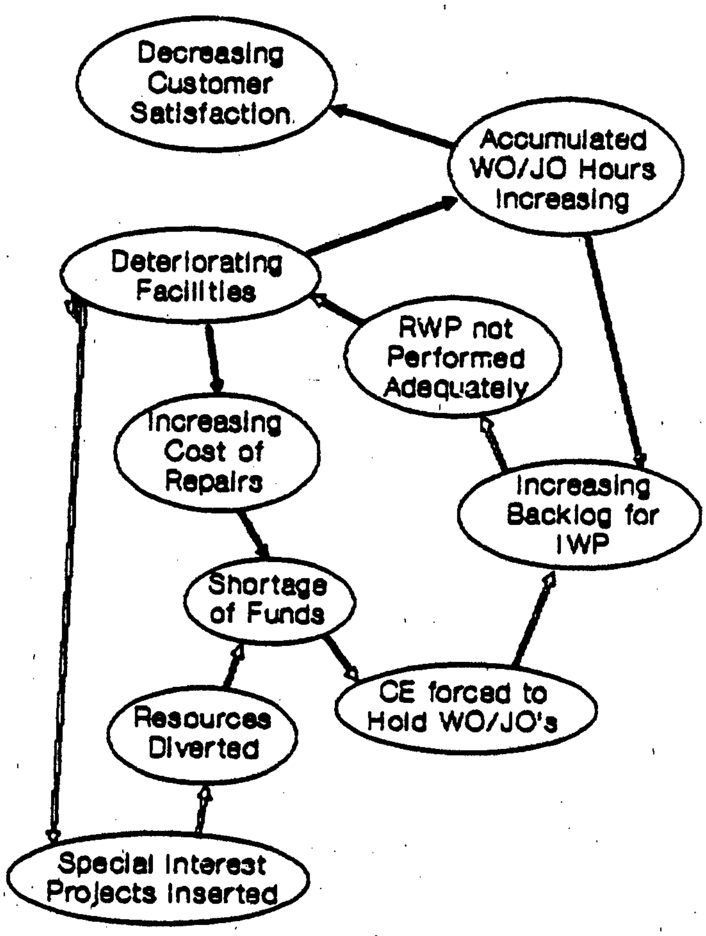

Figure 13. Effect-Cause-Effect Loop #3

<u>The Core Problem</u>

From the effect-cause-effect diagrams above it becomes apparent that the three interconnected loops are causing a decline in customer satisfaction.[1] There are three effects involved in all three loops: deteriorating facilities, RWP not performed adequately, and increasing backlog for IWP. Until construction materials are invented that do not deteriorate with age, facilities will continue to deteriorate and require operations and maintenance actions. Inadequate RWP accomplishment cannot be solved unless more manhours become available in the shops or other work simply is not accomplished. This is not likely to happen unless the IWP backlog is eliminated. Therefore, the only remaining problem that a manager can change is the problem of an increasing IWP backlog.

This problem is the 'what to change.'

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1. There are other cause and effect relationships in the complete effect-cause-effect diagram, but they are not included here in order to simplify the diagrams (16). See Appendix A.

V. What To Change To

This chapter is divided into three sections. The first section uses an Evaporating Cloud to verbalize underlying assumptions causing the core problem. The second section defines the performance measurements needed to change the environment caused by any faulty assumptions uncovered by the Evaporating Cloud. The final section applies the process of ongoing improvement to the Operations Branch by using the Five Steps of Focusing.

The Evaporating Cloud Method

Dr. Goldratt developed the "Theorem of Evaporating Clouds." This theorem requires a problem to be stated precisely and in a specific format. He believes that to state a problem precisely, it must be presented as "a conflict between at least two requirements." This format includes an objective that has at least two requirements with a prerequisite for each requirement. The conflict is present because the prerequisites compete for the same resources (5:2). Figure 14 is a representation of a precisely stated problem.

The purpose of the Evaporating Clouds method is to:

> Induce people to invent simple solutions...away from the avenues of compromise and towards the avenue of re-examining the foundations of the system, in order to find the minimum number of changes needed to create an environment in which the problem simply cannot exist. (11:37)

After establishing the format of the problem, the next step is to verbalize the assumption represented by each arrow. Then attack the validity of each assumption. If any of the arrows in the diagram is shown to be erroneous or irrelevant for the existing case, the assumption is invalid. When any of the assumptions are shown to be invalid, the problem ceases to exist (5:2-5).

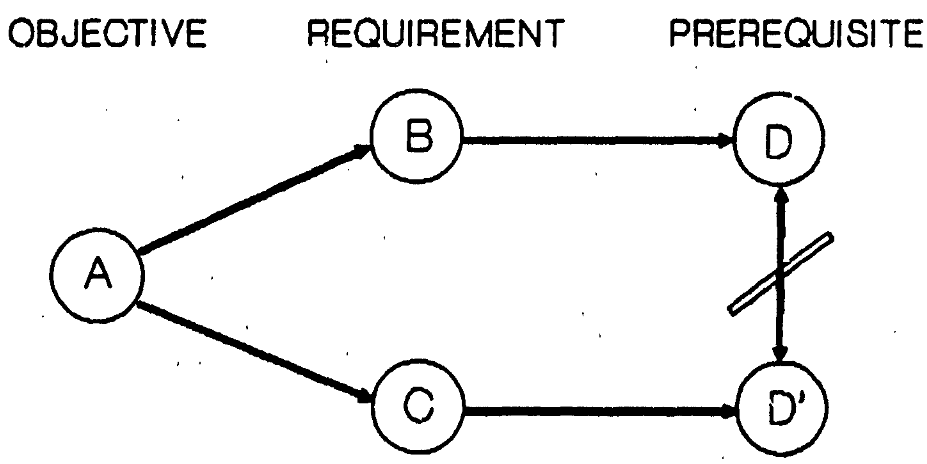


Figure 14. Format of an Evaporating Cloud

<u>The Operations Branch Evaporating Cloud</u>

In the previous chapter the core problem was identified as the 'increasing In-Service Work Plan (IWP) backlog.' To form the solution of this problem into the shape required of the Evaporating Cloud method, the problem must be restated as an objective. The objective is not to have the IWP backlog increase, but to make it decrease. Therefore, the objective statement is to 'decrease the IWP backlog.'

Requirements of the stated objective should be methods that can be used to reach the objective, not to eliminate the problem. Examples of eliminating the problem are: decrease number of WO's, or decrease RWP. Remember the goal of the organization is not to make the problem go away but to 'produce more units of service now and in the future.'

What are methods of decreasing the IWP backlog? What about using SABER? SABER provides a method of contracting out in-service work and therefore, should decrease the IWP backlog. One requirement or option is to use more SABER. This contracting mechanism is available for providing additional manpower to the squadron, but it takes money. (See figure 15.)

Another method is to acquire new construction to replace old facilities. The new construction decreases the in-service workload by replacing old facilities with new facilities which require less maintenance. Another requirement or option is to acquire new construction. Money is also a prerequisite of acquiring new construction. (See Figure 15.)

Increasing the productivity of the in-service workforce should also decrease IWP backlog by providing more hours of productive work. The third requirement is to increase workforce productivity. Typically, productivity increases require more, or better equipment, better pay, or better materials all of which require money. (See Figure 15.)

Each option requires the expenditure of more money. Since more money is not likely to be available, the prerequisites are in conflict over a scarce resource. The prerequisite of more money for each of the requirements completes the first step, formatting the problem. Figure 15 shows the problem in the graphical Evaporating Cloud format.

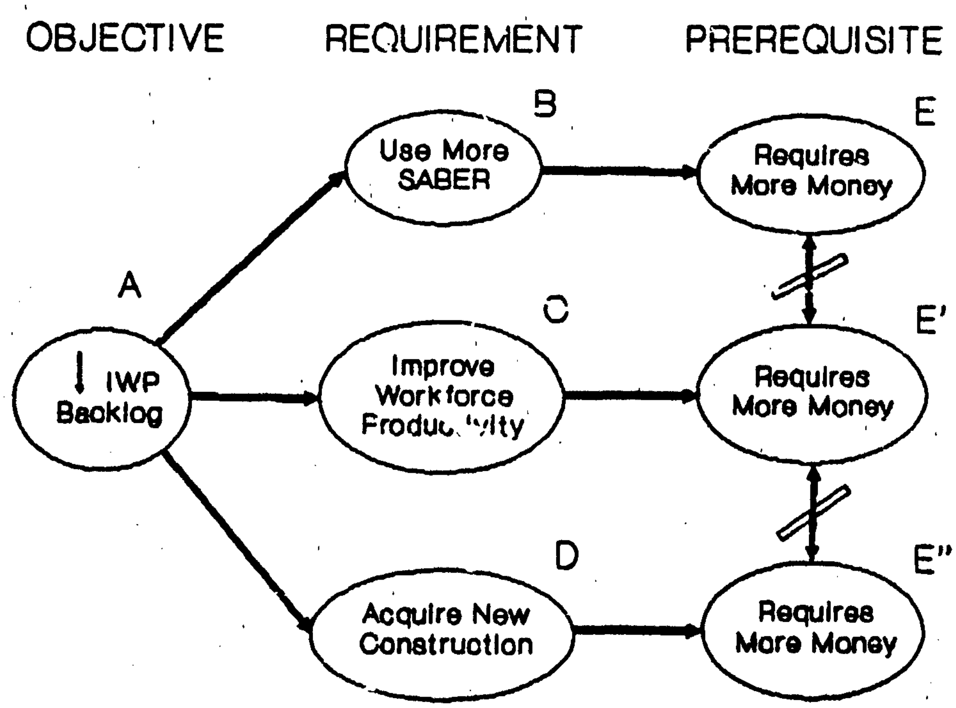


Figure 15. Statement of the Problem

<u>Assumptions</u>. The next step is to verbalize the assumption behind each arrow.

<u>Assumption A-B</u>. The underlying assumption represented by this arrow consists of more than the use of a SABER contract to increase the amount of work performed by

the CE unit. It assumes that increasing the size of the current workforce will increase the units' output. Therefore the assumption is stated as: increased manning will decrease the IWP backlog.

<u>Assumption B-E</u>. Increasing the size of the workforce, either by contract or by direct hiring, cannot be accomplished without more money.

<u>Assumption A-D</u>. Most people believe that if an old facility is replaced by new construction, the cost of maintaining base facilities will decrease. The assumption represented by this arrow is that new facilities require less maintenance, and therefore less manhours, than old facilities.

<u>Assumption D-E''</u>. New construction is undertaken for basically two reasons: 1) replace old facilities, 2) house a new mission or requirement. Since this problem does not pertain to new missions, the assumption here deals only with the replacement of old facilities. The assumption represented by this arrow is: new construction can not be obtained without more money.

<u>Assumption A-C</u>. Most people will agree that improved productivity should decrease a backlog of work. The represented assumption is that the workforce is capable of consistently producing more output.

<u>Assumption C-E'</u>. Most money expended on increasing workforce productivity is spent in one of four

areas: more or improved equipment, increased pay to retain more experienced craftsmen, more expensive materials designed to cut installation time, or management systems to provide more control over the efficiency of the workforce. These expenses are generally aimed at increasing the efficiency of individual shops or processes. The underlying assumption behind these expenditures is that increased efficiency of each individual process increases the productivity of the system.

Attacking the Assumptions. The next step is to attack each assumption. When one is shown to be invalid the problem will 'evaporate.'

Assumption A-B. There is not much to attack here. In some instances more manpower does not necessarily help to solve the problem, but in this case it could help to decrease the size of the IWP backlog. There are other assumptions easier to disprove so this one is not pursued further.

Assumption B-E. There may be some innovative ways to acquire contracts or in-service workers that are inexpensive, but even inexpensive is too much if the extra money is not available. It appears that attacking this assumption will not evaporate this problem.

Assumption A-D. Anyone that has worked in CE when a new facility was turned over from the contractor may question the validity of this assumption. There are often maintenance problems in the facility before the shops find out how the new equipment in the new facility is designed to work. Then there are the users that are not happy with the color of their office and want it repainted. Though these are just a few of the problems that a Chief of Operations must deal with when a new facility is finished, it is probably a good bet that the number of manhours required to keep the new facility operational is much less than what would have been required to bring the old facility up to the standards of the new construction.

Assumption D-E''. Projects allowing private firms to construct and operate facilities on military bases are attacking this assumption (e.g. Contract billeting and military housing constructed by third party and rented to the military). Some of these propositions may be working and decreasing a portion of the IWP backlog. However, if these projects flourish, CE manning will witness a reduction because of the reduction in the square footage of facilities. If the manning is reduced at the same rate as the backlog of work, it is unlikely that a net reduction of IWP backlog will result.

Assumption A-C. More overtime increases availability rates in the shops and appears to increase productivity. More overtime is not only expensive in terms of money, but people get less productive when they work extra hours for weeks at a time.

Assumption C-E'. Most managers currently believe that increasing the efficiency of each process will increase the system's productivity. Is this really true? To break this assumption, there must be a case where the high efficiencies of processes in a system do not lead to higher productivity of the total system.

Have you ever walked into a shop that you knew had a large backlog of work and saw someone sitting reading a paper? What was your reaction? If you asked why the individual was not working you are not alone. This is a common reaction for managers that do not realize that high local efficiencies do not necessarily lead to a high level of organization production. Most people do believe that for the organization to be productive all personnel in the organization must be productive all the time.

An example of a system where high local efficiencies do not lead to high productivity follows (17).

Figure 16 depicts a system that produces a part that starts as raw material entering process A and is processed through each process until it is finished by process E. In this simple example assume there is no downtime for breakdowns or personal breaks and process times are deterministic. Each process can work a full eight hours each day, five days per week.

Process Time (minutes)	5 min	6 min	10 min	12 min	3 min
Production (parts/hour)	12 p/h	10 p/h	6 p/h	5 p/h	20 p/h

Figure 16. Efficiency Example

Assume also that this system is part of an organization that measures the performance of its foremen on the efficiency of their process. In this organization, what is the goal of each foreman? Of course, it is to ensure that their process is always busy producing material so efficiencies remain high.

If each process is always productive, what is the maximum efficiency of each process? Process A can process 12 parts per hour for as long as it can get raw material. So Process A efficiency is 100 percent. Process B can process 10 parts per hour and is supplied with 12 parts per hour so Process B always has material to work on and its efficiency is 100 percent. Process C can process 6 parts per hour and is supplied with 10 parts per hour from Process B so Process C always has material to work on and its efficiency is 100 percent. Process D can process 5 parts per hour and is supplied with 6 parts per hour so it always has material available to work on and its efficiency is 100 percent. Process E can process 20 parts per hour but is supplied only 5 parts per hour and its efficiency is only 25 percent. How would you like to be the foreman of Process E where performance is measured on having a high efficiency but you are supplied only enough material to work 25 percent of the time?

The total number of minutes worked by each process divided by the total minutes of available processing time for the five processes gives the systems efficiency of 85 percent.

Process A - 60 minutes per hour = 100 Percent
Process B - 60 minutes per hour = 100 percent
Process C - 60 minutes per hour = 100 percent
Process D - 60 minutes per hour = 100 percent
Process E - 15 minutes per hour = 25 percent

255 minutes per 5 hours = 85 percent

An additional problem becomes evident after the first day of production, a large amount of inventory builds up in front of Processes B, C, and D. Since Process A produces more parts per hour than Process B can produce, inventory will build up indefinitely in front of Process B. The same scenario is true for Processes C and D. The build up of inventory in front of these processes increases raw material costs and holding costs which will eventually eat away at the companies profit.

Now assume that Figure 16 is part of an organization that measures its foremen based on their ability to maintain the flow of output of the whole system. Now what is the goal of each foreman? To ensure that the succeeding process is not delayed processing time because of their process. Now the foremen must determine the maximum throughput of the system and ensure that they do not cause the throughput to decrease. The throughput is 5 parts per hour because the slowest process takes 12 minutes per part. Processes A, B, and C can easily produce 5 parts per hour which keeps their individual efficiencies below 100 percent. Process D produces at 100 percent and Process E has no trouble producing only 5 parts per hour. The efficiency of each Process and the systems efficiency are calculated below:

Process A -	25 minutes per hour	=	42 percent
Process B -	30 minutes per hour	=	50 percent
Process C -	50 minutes per hour	=	83 percent
Process D -	60 minutes per hour	=	100 percent
Process E -	15 minutes per hour	=	25 percent
	180 minutes per 5 hours	=	60 percent

The system is capable of producing 5 parts per hour in both scenarios which keeps the throughput the same. In the second scenario however, the amount of inventory between the processes is 0 because all processes are producing parts at the same speed. This lack of inventory stacked up throughout the system keeps the organization's investment in raw materials low and holding costs down, both of which increases the organizations profit potential.

In this simple example the organization with 60 percent system efficiency is able to produce the same amount of throughput as the organization with 85 percent efficiency.

Exposed. The simple example above exposes the faulty assumption that increasing the efficiency of individual processes increases the productivity of the system. Now that an arrow in the Evaporating Cloud is broken the problem 'evaporates' if the faulty assumption is replaced with a guideline that does not restate the existing situation.

What is the main difference between the 85 percent efficient organization and the 60 percent efficient organization? The first uses local efficiencies to measure performance of the foremen of the processes and the second uses throughput of the system to measure performance.

Why does this make a difference? When efficiencies are used to measure the foremens' performance, the bridge between local decisions and the organization's goal are not present. In the second part of this simple example it is easy to change the foremens' goals and say they are the same as the organization's goal. It is not so easy with more complicated systems.

With the assumption now exposed as invalid, it is possible to see what is holding the Operations Branch back from becoming more productive. Performance measures, currently used by management, create a gap between global and local goals.

It becomes obvious now that what is needed is new performance measures that bridge the gap between the foremen's goals and the organization's goal. The performance measures proposed by TOC are throughput, inventory, and operating expense. Recall that throughput is the rate an organization produces output, inventory is the money invested in generating throughput, and operating expense is the money spent by the organization to turn inventory into throughput.

Performance Measurements

In this section these performance measures are first defined in terms of the services provided, the budget allotted, and the expenses acquired by the Operations Branch. It then discusses the relationship between throughput, inventory, and operating expense and how they are used to form the bridge.

Throughput--Defining a Unit of Service. There are four services (products) CE provides to its customers:

1. Operations - utilities in the way of electricity, steam, water, sewage, base roads, etc.

2. Recurring work program (RWP) - periodic maintenance of facilities, utilities, and pavements designed to slow the normal aging process.

3. Job orders (JO) - single shop maintenance and repair work with some limited minor construction.

4. Work orders (WO) - multi-shop work used for renovations, repair, and upgrading facilities.

The first three services can be viewed as "dissatisfiers."--As long as the service is provided there is no problem, as soon as it falters or the service is degraded, the overall perceived service provided by CE is diminished. These products cannot help CE improve its service to the customers. They can only detract from its service by their non-performance.

Operations. Operations is a dissatisfier. There is no way for operations to add positively to the level of customer satisfaction. Operations cannot provide more service than the customer needs. On the other hand if CE stops providing a service for any amount of time, the level of customer service is certainly lowered. As long as uninterrupted electrical service continues to be provided, customers are satisfied with the service. However, if electricity is cut off for any amount of time, the quality and quantity of service is degraded. Is a customer more satisfied with the level of service provided by operations if CE provides more electricity than the customer needs? Probably not.

Figure 17 shows a scale of customer satisfaction with zero being neutral. Negative customer satisfaction is portrayed by the negative (-) sign on the continuum while positive or increased customer satisfaction is portrayed by the positive (+) sign. The only possible effect of the product operations is to subtract from the neutral position if the service is not provided.

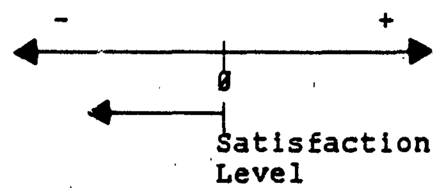


Figure 17. Operations' Contribution to the Goal

<u>Recurring Work Program</u>. The Air Force's RWP is a program designed to ensure preventive maintenance is accomplished on base facilities as needed in a timely manner. According to AFR 85-2, RWP includes work needed to prevent critical facilities, equipment, and utilities from breaking down, and includes recurring requirements such as pavement cleaning and grass cutting (8:49).

As with operations, RWP is a dissatisfier. There is no way to add to the level of customer satisfaction. Cleaning the streets more often or cutting the grass every day will not add to customer satisfaction. If the RWP is not performed however, CE phones are ringing with requests (orders) to perform the work.

RWP performed on equipment, is not usually visible to the customer. This RWP is probably more important because it can effect the customer's mission support capability. This RWP is performed on facility equipment such as air conditioners, ventilation systems, etc. As long as the RWP on the customer's air conditioner is performed and it continues to operate properly, CE performance is not improved, but let the compressor fail and customer satisfaction is degraded. If the compressor is fixed immediately, CE has continued to provide its service with only a little degradation. However, if the compressor is down for days the customer is certainly not satisfied and may have doubts as to the quality and timeliness of support.

Figure 18 depicts the effect that not accomplishing RWP has on the level of customers satisfaction. A measurable unit of performance is subtracted from the neutral position for each RWP action not performed when required.

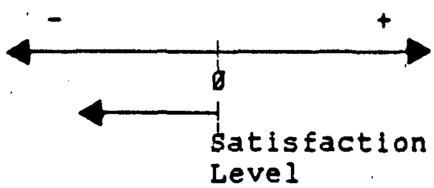


Figure 18. RWP Contribution to the Goal

Job Orders. Not necessarily all, but certainly most JO's can be classified as dissatisfiers. There are generally three types of JO's:

1) something out of CE's control is broken or doesn't work properly and the customer needs it fixed.

2) something within CE's control is broken and the customer needs it fixed.

3) the customer submits a new requirement.

These three JO types are not separately identified within the CE information management system. An adequate analysis of the different types would be a long and tedious task requiring review and classification of thousands of JO's. However, by definition, the bulk of the first two types of JO's are classified as emergency or urgent JO's. These are JO's that can be classified as dissatisfiers, the type of requirement that cannot add to customer satisfaction even if more of it could be accomplished. For example, a functioning commode does not improve nor impair a customers view of CE's performance. But, if the commode is out of service and CE can not repair it immediately, service is degraded. The third type of JO's is not seen as a typical JO since it is submitted as a new requirement. This type of JO is treated as a satisfier and is included with the WO's.

In the case of repair JO's there are two levels of performance, one for the inconvenience of the call in the first place, and another if CE can not immediately respond to correct the situation prompting the call.

Figure 19 depicts the JO that is completed by CE promptly. A measure of customer satisfaction is subtracted from the neutral position because the very requirement of the JO call decreases customer perception of CE performance.

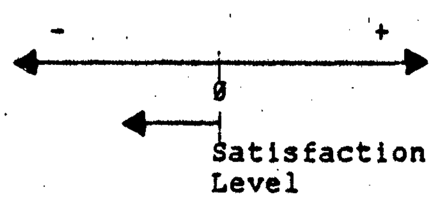


Figure 19. Completed JO's Contribution to the Goal

In Figure 2Ø the size of the line pointing to the negative side of the continuum is due to the nonavailability of immediate response. CE could not respond quickly enough for the customer so the amount of customer dissatisfaction increases thereby, decreasing the level of CE performance more than the case where CE is able to respond immediately.

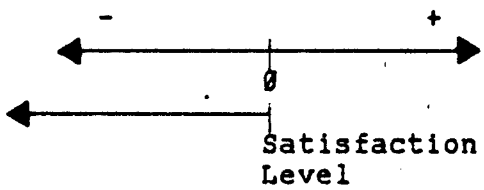


Figure 2Ø. Uncompleted JO's Contribution to the Goal

Work Orders. The only product of the four that can be clearly classified as a "satisfier" is the WO. Included here is the JO submitted for a new requirement. This work can be considered as a mini-WO. When a customer submits a WO, there is some specific, new need which the customer desires. When the WO is completed, there is a resultant increase in the quality of service provided to the customer. However, if the WO is not accomplished when needed, customer satisfaction will diminish. The WO is the most visible product for most CE customers.

Figure 21 depicts the increase of customer satisfaction due to the prompt accomplishment of the new need desired by the customer. The magnitude of the customer satisfaction added to the neutral position is dictated by the size of the

WO, number of customers serviced, and the number of shops involved.

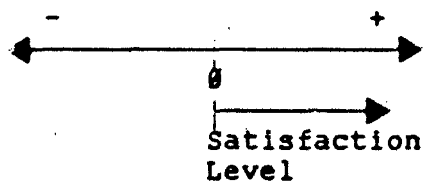


Figure 21. WO's Contribution to the Goal

Units of Measure. Now that the products provided by CE and their effects on customer satisfaction are defined, what is the unit of service provided? There are currently none defined that are able to adequately measure all four CE products. However, in order to facilitate future discussions of performance measures for CE, the hypothetical unit of 'utility' is defined as being equal to one unit of service provided to CE customers--its throughput.

Inventory. Inventory for a CE organization involves two type of constituents: material and paperwork. The material part of inventory includes materials for WO's not yet complete, residual holding, emergency stocks, and shop stocks. To understand the paperwork inventory, visualize the individual pieces of paper in place of parts being processed. The pieces of paper could be orders being processed by an office that two or more personnel must process before the 'product' becomes output. The more orders in the system the larger the inventory within the system.

A paperwork system can get clogged with inventory just as easily as a production organization with stacks of inventory awaiting processing by its processes. The more inventory in the system the longer each piece waits for the actual process to be performed.

Operating Expense. Operating expense for a non-profit service organization is not much different than that of a for-profit production organization. Each spends money on things required to turn inventory into throughput. Items such as shop tools, equipment, office supplies, civilian labor budget, and CE facilities are examples of operating expense.

Some may argue that equipment and facilities are not operating expense because they are investment items and therefore should be considered inventory. However, as far as CE is concerned, even investment items are operating expense because CE does not receive the money resulting from the sale of old or salvaged equipment.

Performance Measurement Relationships

For-profit organizations are able to use net profit (Throughput - Operating Expense) and return on investment (Net Profit/Inventory) as bottomline measurements of the companies' progress towards its global goal of making money. This is possible because all three performance measurements;

throughput, inventory, and operating expense, are measured in units of dollars.

In the Operations Branch, throughput and parts of inventory can not be measured in dollars. Since it is not mathematically possible to add or subtract unlike units, there is a need to develop new relationships between the performance measurements. These relationships must present a way for managers to determine if the organization is progressing towards its global goal. Examples of bottomline measurements are:

$$\frac{\text{Throughput (utilities)}}{\text{Operating Expense (dollars)}} = \text{Utility per expense dollar}$$

$$\frac{\text{Throughput (utilities)}}{\text{Inventory (dollars)}} = \text{Utility per investment dollar}$$

Though the unit of throughput can be used as a measurement itself, it may be useful to monitor the ratio of throughput to operating expense or investment. Such ratios give the manager an indication of the amount of benefits provided to the customer for the expense incurred or investment required.

When using a ratio as an indication of performance one must keep in mind that a change on the numerator has a more dramatic effect on the value of the ratio than a like change in the denominator. An example is the ratio 5/10 = 0.5. Increasing the numerator by 1 increases the ratio to 6/10 =

0.6. However, decreasing the denominator by 1 increases the ratio to only 5/9 = 0.55. This simple example shows that an increase of utility has more positive effect on the utility per expense than a similar decrease in the operating expense.

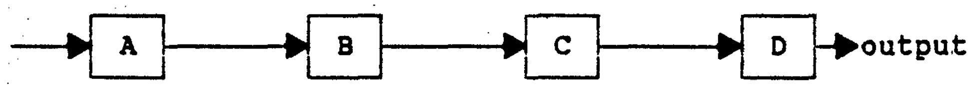
The performance measures throughput, inventory, and operating expense and their interrelationships provide the piers for the bridge needed by all levels of management. These measurements are useful only for global measurement of an organization's goal and for performance measurement of the constraint of the system since the constraint controls the rate of output of the system.

How are the non-constraints measured? The last four steps of the Five Steps of Focusing provide an answer to this question as well as providing the rest of the bridge.

The Five Steps of Focusing

This section applies the Five Steps of Focusing to the Work Order (WO) program within the Operations Branch. It first describes how to identify a constraint through the use of a simple example that shows the logic behind identifying a constraint. That logic is then used in an attempt to identify the constraint in the Operations Branch. The other four steps, exploit, subordinate, elevate, and inertia are also described in terms of Operations Branch examples.

Identifying the Constraint in a Simple System. Another simple system of processes is used to logically derive a method of finding the constraint within a system. Figure 22 is a system of four processes where Processes B, C, and D are dependent on each of the preceding processes. In this simple example assume there is no variance in process times.



Process Times 2 min. 3 min. 5 min. 2 min.

Figure 22. Example of a Line System

To determine which is the constraint or the slowest process, start with Process D. Its processing time is 2 min/part so it can produce 30 parts per hour. Parts are provided from Process C at only 12 parts per hour so Process D is limited to 12 parts/hour by Process C. Process B can produce 20 parts/hour and process A can produce 30 parts/hour. Both can produce more than Process C. The calculations of the parts produced per hour for each of the four processes is shown in Figure 23. By comparing the process times of each process, determine the constraint. It should be obvious that Process C is the slowest process and limits the throughput of the system to 12 parts per hour.

Since Process A produces parts faster than Process B, an inventory of parts will pile up in front of Process B. The same is true for Process C. Process D will normally not have a backlog because it can produce more than twice the rate of Process C. The size of the backlog in front of each process is a function of the processing time of that process

Process A

$$\frac{60 \text{ min/hour}}{2 \text{ min/part}} = 30 \text{ parts/hour}$$

Process B

$$\frac{60 \text{ min/hour}}{3 \text{ min/part}} = 20 \text{ parts/hour}$$

Process C

$$\frac{60 \text{ min/hour}}{5 \text{ min/part}} = 12 \text{ parts/hour}$$

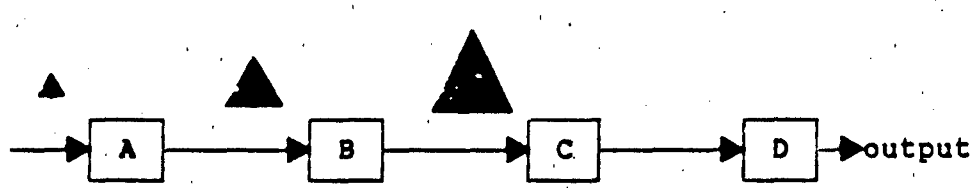
Process D

$$\frac{60 \text{ min/hour}}{2 \text{ min/part}} = 30 \text{ parts/hour}$$

Figure 23. Process Times

and the processing times of the preceding processes. Therefore, it is logical to assume that the constraint process will have the largest pile of inventory awaiting processing. This inventory is called a backlog.

Figure 24 shows the location of the largest backlog in front of the resource constraint.



Process Times	2 min.	3 min.	5 min.	2 min.

Figure 24. A Line System with Backlogs

<u>Identifying the Constraint in the Operations Branch</u>. Earlier in this chapter performance measurements were

discussed and determined that WO's and some JO's are the only products provided that increase the output of the Operations Branch. Since the goal is to increase the output of the organization; RWP, Operations, and JO completion are necessary conditions to staying at the neutral position on the scale of customer satisfaction. The only service that increases the level of customer satisfaction is the WO. Therefore, the system to look at in the Operations Branch is the WO program.

Most people have their own ideas as to where the constraint is located. Some of the popular constraints are Material Control, money, and manpower.

Is Material Control the constraint because of extended delays in getting materials and supplies? If Material Control is the process limiting the overall performance of the organization, its processing time must be longer than the other processes in the system. Past research has determined the response time for material delivery in a Government Operated Civil Engineering Supply Store (GOCESS) to be 18.6 days with a standard deviation of 14.6 days. It was further found that only about 3% of the requirements were received after 50 days (18:35).

Though the processing time varies greatly in Material Control, the number of WO's that can be processed at one time is large. Once the material is ordered the rest of the processing time is simply waiting for material delivery.

Material Control seldom has a backlog of WO's waiting to be processed unless money is short.

Is money for materials the critically short resource? What about the large quantity of money tied up in inventory? It is money spent on materials required for future work and is stored in the warehouse waiting to be used. According to Capt Robin Davis, the approximate holding cost for materials is 33% and the Air Force pays approximately $15.5 million per year for CE inventory holding costs (18:2). Another policy that wastes huge amounts of money on materials that do little to increase the performance of the organization is the lump sum given to Material Control near the end of the fiscal year with the stipulation that it is obligated in two days. This practice leads to the expenditure of the money, not on materials that will increase the current output, but on materials that increase the inventory, thereby increasing holding costs.

Is manpower the critically short resource causing backlogs in more than one process? The example at Figure 24 shows that backlogs appear in front of numerous processes because the preceding process is actually producing more than the system can produce. If personnel were added to Processes A, B, and D, the total output of the system would not increase by one product. Only by increasing personnel at Process C will output increase. The problem is not necessarily not enough manpower, but maybe not enough manpower assigned to the right process.

The Work Order Program as a Line System. To put the WO program into the perspective of TOC, look at it as a system made up of a number of processes. Process A is the Customer Service Unit where the 'order is received.' Process B is the approval process, Process C is Awaiting Planning, Process D is Planning, Process E is Awaiting Funds, Process F is Material Control, Process G is Awaiting Scheduling, Process H is Scheduling (shops are scheduled to accomplish the work), and Process I is Close Out actions. The material processed by this system is the piece of paper called a WO. Figure 25 represents this system of processes that a WO must be processed through for completion.

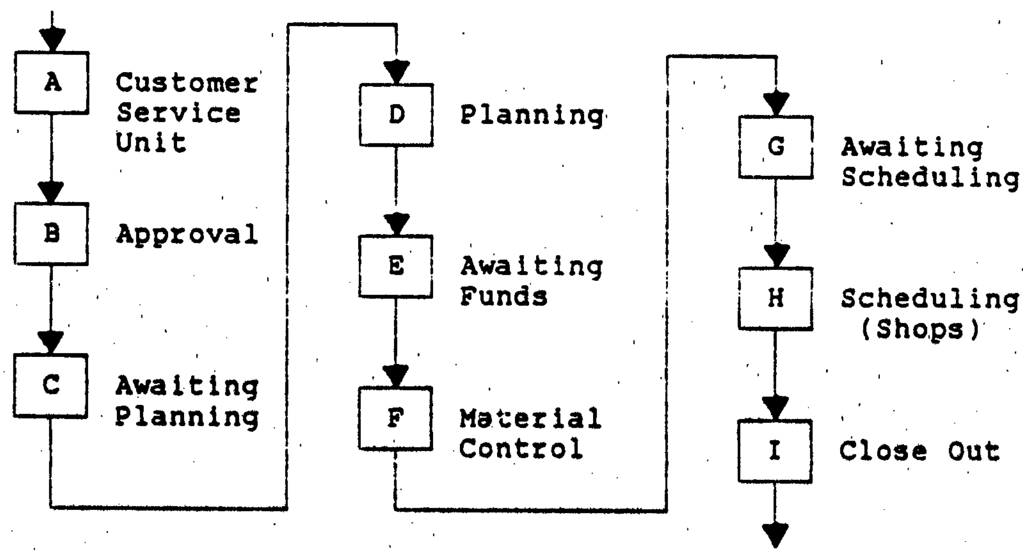


Figure 25. Work Order System

An attempt to identify the backlog of WO's in front of each process is fruitless because the information stored in the Work Information Management System (WIMS) is not conducive to this type of analysis. WO's are assigned to a tracking indicator (PLN, CSU, MAT, etc.) with no indication of how long the WO waits for processing or is actually processed. This is not due to an oversight by the programmers, but to the fact that this type of information is not currently requested by managers (13).

In his latest book, The Haystack Syndrome, Goldratt recognizes that managers have more than enough data, but still can not seem to get the information they need (19:3). Which is the case in this situation. Plenty of data is available in the WIMS database, but it is not the information needed to find the constraint of the WO system.

By definition, a constraint limits the output of a system. Maybe the identification of the constraint can be accomplished by verbalizing how the system works?

The CSU receives a WO request and it takes less than a day to process it. If the WO is not properly coordinated, it goes to Process B. The actual process of approval at each stop does not take long, but the travel time between coordination offices and the waiting time before being processed can vary greatly. After the coordination is complete, Planning establishes a shotgun estimate for approval purposes. The Approval process itself is less than a day, but approval meetings meet about once a week so the waiting time again is the largest part of this process.

Once approved the WO is held at Process C, Awaiting Planning. The Chief of Requirements looks at a number of requirements before a WO is sent to Planning. These include, which shops will require work in a future month, money required to purchase the materials required, and the workload of the Planning Section.

Most of the waiting time prior to the WO being processed by the Planning Section occurs in Process C so almost all of Process D is processing time.

When Process D completes its process on the WO, the WO moves to Process E, Awaiting Funds. This process is the accumulation point of the waiting time for Process F, Material Control. The material can be ordered in a matter of only a few days once the WO is released from Process E. The remainder of the processing time depends on the response time of the particular purchasing arrangement in use at the base.

After all material is received for a WO, it moves to Process G, Awaiting Scheduling. This process is the accumulation point of the waiting time for Process H, Scheduling. Once the WO is released to Process H, the work is actually scheduled for completion and the shops start construction.

Process I, Close Out, consists of turning in residue materials, Real Property coordination, if required, and the Chief of Operations signature. Processing time is very short and normally accomplished in groups of WO's at a time.

With the system completely defined, ask the following question: Increasing the output of which process in the system will increase the throughput of the system?

In order to answer this question, start at the last process and, working backwards, ask another question: will the system's throughput increase if the preceding process processed inventory faster?

Starting at Process I, will throughput through Process I increase if Process H processes faster? Since the Closeout process time is very short and can be accomplished in groups of WO's at one time, It appears that Process I can process more.

If Material Control could purchase materials faster and process more WO's, would the systems' throughput increase? It is doubtful this would happen as long as Process G has WO's assigned to it. Process G is a holding process and only has WO's assigned if Process H does not have the manhours available to perform the work required.

Will Material Control output increase if Planning processed WO's faster? This is also doubtful as long as Process E has WO's assigned to it. Process E is the holding process and only has WO's assigned if Material Control cannot purchase material or if manhours are not expected to be available.

Will the approval of more WO's allow Planning to process more? Not as long as Process C has WO's assigned since it is the holding process before progressing to Planning. Process C is typically the release process for the rest of the system. When middle managers expect money and manhours to be available, a WO is released to Planning for processing. Most of these releases are contingent on the expected availability of shop manhours.

The last question in this analysis deals with increasing the output of Process A. If more WO's are submitted to the Customer Service Unit, will the throughput of the system increase? Most managers will agree that increasing throughput is not a problem of not having enough work to perform.

So which process is the constraint? Whichever one that will increase the systems' throughput if the processing capability is increased. Some may believe Planning is the constraint, or Material Control is the constraint, or a craft shop is the constraint. The constraint could be different for different organizations. The manager should pick one as the constraint and manage it by the rest of the "Five Steps. If the process established as the constraint turns out not to be the constraint of the system, a backlog of work quickly increases in front of the real constraint.

For the purpose of further discussion a craft shop process is considered the constraint.

An Operations Branch Shop as the Constraint. This discussion will not get into the reason why a shop may be the constraint, only which shop may be the constraint.

Some of the information needed to determine the location of the constraint shop is available in the WIMS. The estimated number of manhours required for completion of each planned WO is stored by shop in the MWCN file. From this information it is possible to retrieve an estimate of the accumulated manhour backlog for each shop. The accumulated backlog of manhours is not restricted to the manhours required to complete the WO's awaiting scheduling. It refers to the estimated manhours required to complete all planned WO's.

There are three items missing from making the accumulated backlog effective for determining the constraint. They are 1) approved WO's do not have estimated manhours until they are planned, 2) RWP actions that are not accomplished can not be included, 3) there is no way to include JO's because they are not estimated unless materials are required and then the estimate is not very accurate.

The COBOL program in Appendix B totals the non-completed WO hours using data on the DAT001 volume; MWOXDATA library; and the MWOA and MWCN files. The program also totals all direct hours for the month requested from the MIWH file.

The relationship between the processes' backlog and its processing time is described in the example above. This relationship is used now to graphically portray the ratio between the non-completed WO hours, from the MWCNSUM program, and the total monthly direct hours for each shop. Figure 26 shows the five shops with the highest ratios. This ratio is equal to the number of months work each shop has planned if no work but WO's are to be accomplished.

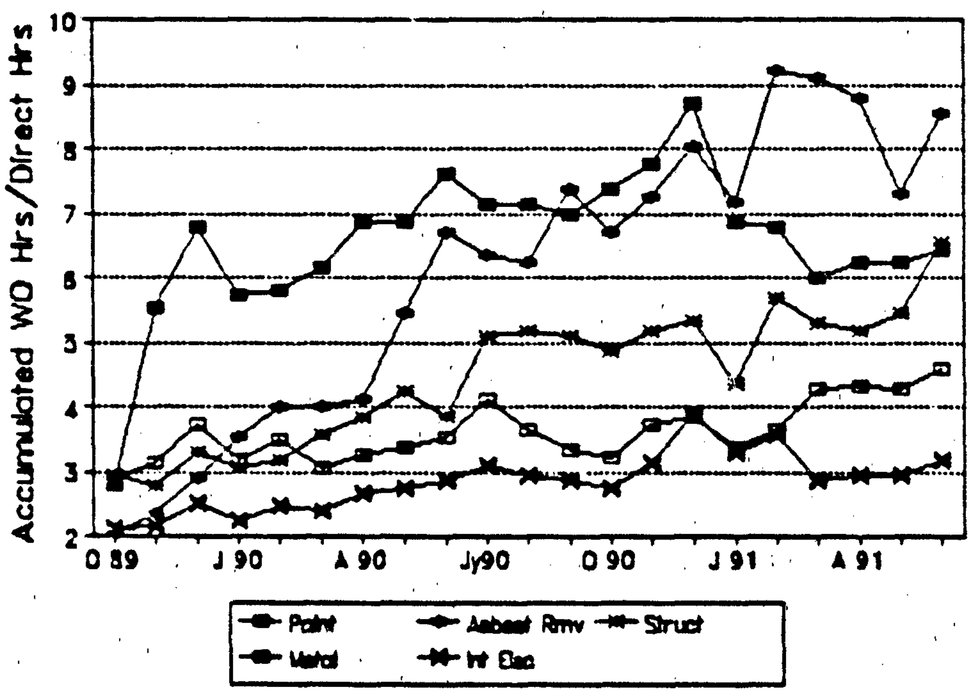


Figure 26. Graph of Backlog WO Hours to Actual Direct

At most bases, the Chief of Requirements directly controls the WO's released to Planning. At Wright-Patterson

AFB, the Chief of Requirements controls the appearance of the graph in Figure 26. If WO's are released that are expected to require a large number of manhours for the Structures Shop, the accumulated backlog increases. It is also easy to make it appear that a shop is catching up if WO's that involve that shop are not released to Planning and therefore, do not appear in the accumulated backlog.

At Wright-Patterson AFB, the Chief of Requirements closely manages the amount of work planned for the Interior Electric shop. The planned workloads for the Asbestos Removal, Metal, and the Paint shops are not considered when deciding which WO is to be planned next. The workload of the Structures Shop is monitored to ensure enough work is planned to keep the shop productive, but not closely controlled (16).

The control exerted over the planned WO manhours for the Interior Electric Shop will keep the accumulated manhours at a manageable level for the subject shop and thereby not show the large backlog expected of a constraint. This control and the problems described earlier severely limit the ability of the COBOL program to help in identifying the constraint of the Operations Branch.

<u>Establish a Constraint Shop</u>. The person in the best location to determine the constraint shop is the Chief of Requirements, or whomever has direct control over what work is scheduled and what WO's are released from the

Awaiting Planning process. The personnel in control of releasing WO's should have intuition in finding and establishing the constraint. They will have a good feel for which shop would have the greatest impact on increased throughput if more work could be processed through it.

To increase the throughput of the whole process, pick the constraint shop and manage the rest of the system in accordance with the following four steps. If the shop turns out not to be the constraint it will become evident by the increasingly large backlog in front of the real constraint.

Exploit the System's Constraint. Once the constraint is determined, make sure the constraint shop's efforts are not wasted. Wasted time for a constraint occurs when a worker makes more than one trip to a job or must wait for another worker, or do paperwork which could be done by someone else. Every minute the constraint shop is delayed, is a minute delayed for every person in the system.

Two possible methods of ensuring the constraint shop is not delayed are: 1) perform quality control inspections and correct any deficiencies before the constraint shop starts their work. 2) ensure the constraint shop performs work needing attention now.

Subordinate Non-constraints. This step deals with the management of the processes that are not constraints. Non-constraints must process items the constraint will eventually process. Subordinate the non-constraints by ensuring that they supply everything needed by the constraint, but not more than is needed. Many WO's require more than two shops to coordinate their actions to produce a quality project. Non-constraint shops working a WO with the constraint shop should ensure the work place is ready for the constraint shop when they arrive. The constraint shop should not have to wait for the non-constraint to finish a task before they can proceed with the work.

Tasks assigned the constraint shop that do nothing to increase the throughput of the organization should be eliminated or assigned to another shop. Such tasks in an Operations Branch include persons from the constraint shop performing additional duties. Reassigning these duties to personnel in non-constraint shops may not seeem fair, but being fair is not part of the goal.

Elevate the Constraint. After the two previous steps are completed, try to break the constraint. Get more personnel assigned to the shop, pursue cross-training of personnel from non-constraint shops, or acquire over-hires. By definition, any increase of the capability in the constraint shop will increase the throughput of the organization towards its goal.

Becareful of Inertia. If the constraint is broken in the previous step, throughput will not increase any further. The performance will be limited by another process. The constraint will move.

While managing the system based on the location of the first constraint, many formal and informal rules are derived and followed. Inertia occurs if management does not recognize the constraint has moved and continues to manage by the old rules. These rules must be examined when a constraint is broken or policy constraints will limit production. In order to prevent this, the last step of this process is to go back to step 1 and start over again.

VI. How To Effect The Change

All managers can remember a time when a new productivity improvement procedure was directed by upper management to be implemented. Most felt, "the improvement will not work because our section is different."

This chapter discusses how this happens and how an organization can be induced to create and implement their own improvements.

Past Management Policies

To illustrate the negative effects of the implementation method normally used by management today, examine the last management philosophy you were told to implement. Did the performance of your organization improve dramatically because of it? Did it continue to improve? Or did the managers, directed to implement the new philosophy, claim that the procedures would not work in their areas? This is an example of the emotional resistance to change briefly discussed in Chapter III.

Unless the new philosophy was 'championed' by someone in the organization who really believed in the implementation, the new philosophy just became another item to report to the boss about. Even if the champion succeeded in effecting a change within the organization, what happened when the champion was promoted out of the organization?

More than likely the improvement process stagnated because no one else wanted to take over as the champion of the philosophy.

How could this new philosophy be implemented and continue on without a 'champion'? If everyone in the organization decides for themselves that the new philosophy is needed and it will work, there is a chance.

The Socratic Approach

The Socratic method does not provide answers, it provides an individual with questions that are designed to provoke a solution from the individual. If an individual feels ownership of a solution they are more likely to implement the solution than if the solution is given as constructive criticism.

By using the Socratic method a manager instills the 'emotion of the inventor' by convincing the individual that they invented the solution to the problem, or they believe the new management philosophy is needed.

It is not enough however, to convince individuals of the need for change, it must occur at all levels of the organization and gain a group consensus. Quoting from The Race:

> ...merely presenting the appropriate rules and procedures to a group will not ensure their acceptance. Such a presentation needs to include the entire step-by-step derivation of this approach.

> Consensus will be reached only if this derivation starts from a generally agreed-upon picture of the situation...and proceeds using very precise, well-defined arguments, making sure that no gaps or even perceived flaws leave an opening for misunderstanding. The logic must be so strong that it is perceived as common sense. (6:149)

With the majority of the organization convinced that the improvement is not only good but vital for the existence of the organization, a process of ongoing improvement can exist.

Implementation

There are two ways to implement Theory of Constraints (TOC) in an organization. The first method, represented in Figure 27 by the Procedure Curve, shows the path of improvement over time when only the techniques and procedures of TOC are implemented. The second method, represented in Figure 27 by the Thinking Curve, shows the path of improvement over time when the thinking processes are implemented. These thinking processes represent a change in the culture and focus of the whole organization and take more time to implement.

If the person starting the implementation of TOC in an organization is not the Commander, the first step is to get the Commander's full support. As a minimum the Commander should read The Goal and commit to implementing the process of ongoing improvement. Initiating this process in a squadron without the full support of the Commander will

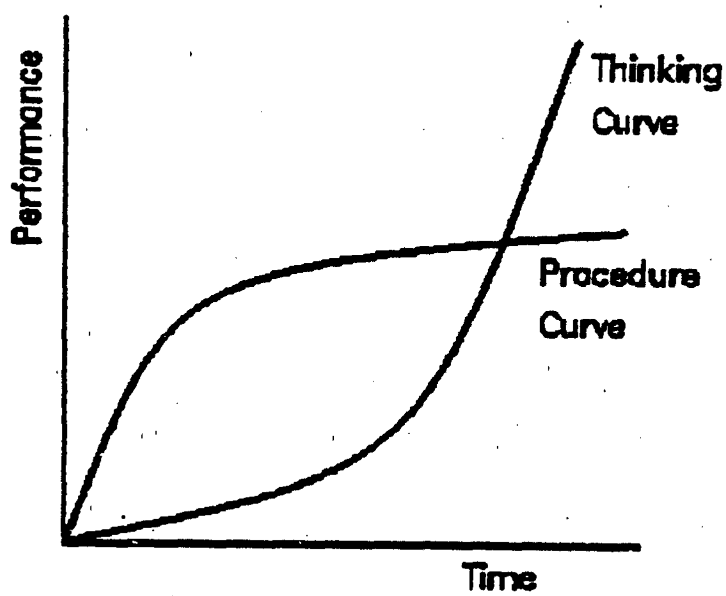


Figure 27. Performance Curves

cause improvement to stagnate after processes are incorporated (follow the Procedures Curve). The full support of the Commander must be visible to the whole organization if the TOC thinking process is to be implemented.

After gaining the Commander's support, or if it it the Commander trying to implement TOC, a suggested method of implementation is described. The steps described below are adapted from literature distributed in training seminars by The Avraham Y. Goldratt Institute (20).

The first step is to get the Commander and Branch Chiefs to read The Goal and attend a two hour presentation. The focus of this presentation is to persuade the top management to move from the "Cost World" thinking to the

"Throughput World," or Mission World thinking. The intent of this meeting is to:

1) Gain a consensus of the top management personnel that this is the method to take.

2) Gain access to the whole organization in order to generate consensus throughout the organization.

The second step consists of a one day seminar for the section chiefs and shop foremen. The Commander starts the seminar by stating that management is investigating this management philosophy and wants to expose it to the organization before pursuing it further. The opinions of the people attending is critical to continuing the implementation. Without their support, the implementation is limited to the Process curve of Figure 27.

The seminar consists of defining the performance measurements, throughput, inventory, and operating expense; convincing people that verbalizing their intuition will help provide effective, simple solutions to problems; the process of change, What to Change, What to Change to, and How to Effect the Change; and finally the process of ongoing improvement in the form of The Five Steps of Focusing.

After this seminar, the attendees provide their opinion of this approach. Management should proceed with implementation only if a large concensus exists among the attendees to continue exploring this philosophy.

The third step is a series of one day work shops for section managers. The financial managers, engineers, shop foremen, Material Control managers, and Production Control managers all attend separate workshops. The workshops incorporate computer simulations related to the specific sections. The process of change and the Five Steps of Focusing are used extensively throughout the day in order to institutionalize the thinking processes for all attendees.

VII. Conclusions

This chapter presents a summary of the research effort, conclusions, and recommended future research.

Summary of Research Effort

This research introduces the Civil Engineering (CE) manager to the Theory of Constraints (TOC) management philosophy and to show that this process of ongoing improvement is applicable to the Operations Branch.

The ground work is laid by introducing basic definitions and concepts on which more complex procedures and thinking processes are built. This includes redefining the mission of Civil Engineering in the framework of a measurable goal for the organization.

The Effect-Cause-Effect analysis allows a manager to verbalize the causes and effects of existing situations that lead to the core problem. This core problem is then analyzed by verbalizing assumptions that are generally accepted as truth and expose the outdated assumption that restricts the output of the organization.

The reader is then lead through an analysis of CE from the perspective of a work order (WO). This analysis consists of the process of ongoing improvement by using the "Five Steps of Focusing."

Finally, the reader is introduced to a method of introducing this philosophy in an organization. Not by getting top management to direct is use, but by eliminating the emotion of resistance to change in the organizations' personnel.

Findings

1. Top CE management should establish a goal for daily, peacetime operations. The goal derived in this research is the view of one of CE's middle managers not in a position to establish a global goal for all of CE.

2. The goal must be measureable. Performance measurements that direct middle managers' decisions towards the goal is mandatory. Any other performance measurement judges decisions after the effect on the goal.

3. CE must be committed to a process of ongoing improvement or be doomed to continually increasing deficits between base requirements and resources to meet those requirements.

4. The process of ongoing improvement must be incorporated socratically. As a middle manager with experience in downward directed management applications, they are often used only for reporting purposes. Unless the manager believes in the management philosophy, new approaches are doomed.

5. One middle manager in an Operations Branch believes this approach "has potential to work" but the problem is getting upper management to agree (16). This is a similar complaint heard in many organizations attempting to implement a process of ongoing improvement (12).

<u>Conclusions</u>

1. CE has three effect-cause-effect death spirals which decrease customer satisfaction. Customer satisfaction cannot be increased until these death spirals are eliminated.

2. In order to eliminate the death spirals, the local performance measures must be in line with the organization's goal.

3. Customer satisfaction will only improve by increasing the throughput of CE.

4. Using the Five Steps of Focusing on the work order system is the only way to improve customer service without spending more money.

5. Establishing a process of <u>ongoing</u> improvement must be implemented with the Socratic method. When the people in an organization decide for themselves that a change is needed it will occur much more quickly than when it is directed.

Recommended Future Research

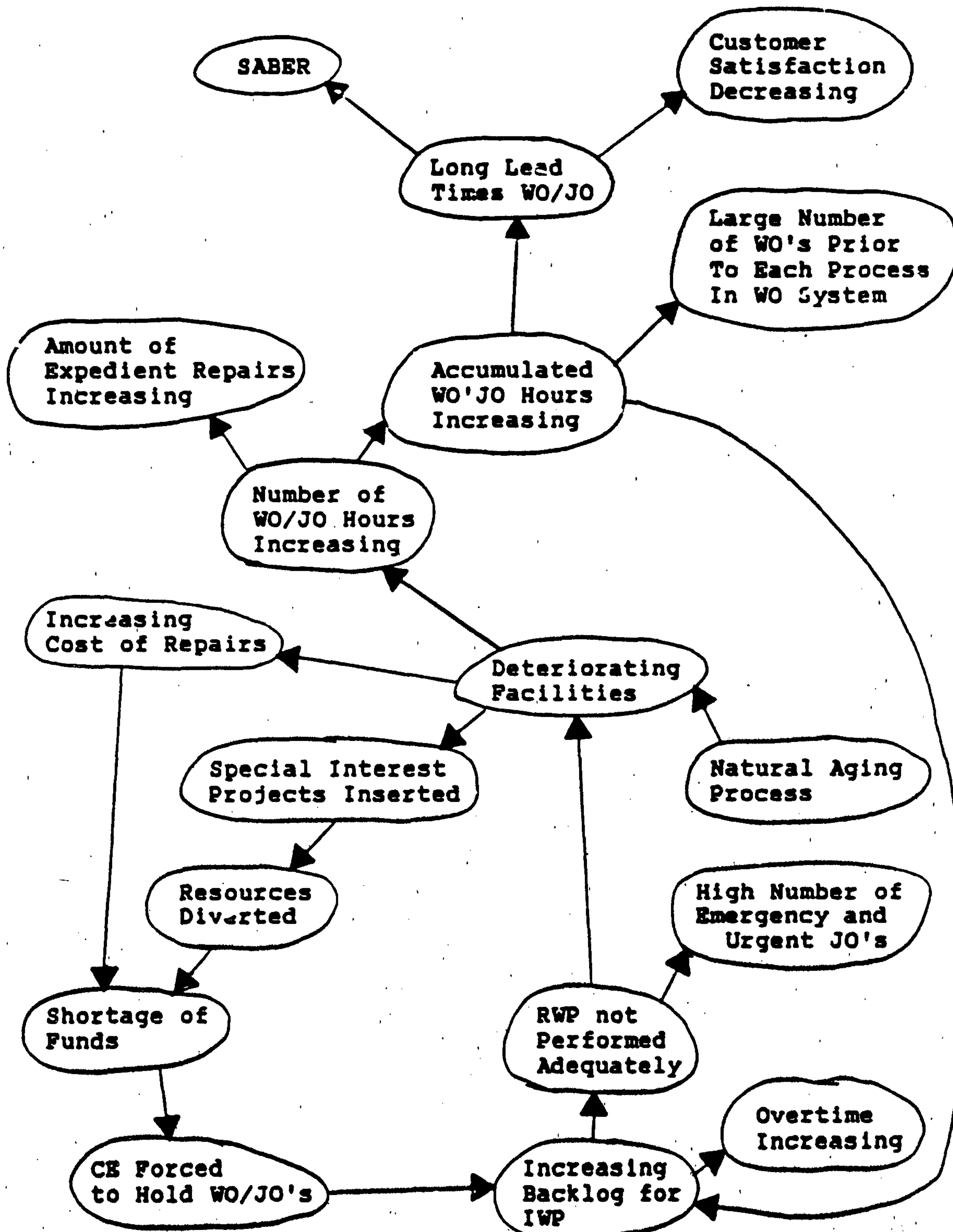
1. Perform an in-depth study in conjunction with senior CE management to define a measurable goal and a unit of performance measurement for CE.

2. There are six competitive edges resultant from lowering inventory in an organization: Reduced time for engineering improvements to reach customers, improved quality, increased profit margin, reduced investment per unit of throughput, improved due date performance, and reduced quoted lead times (6:36). What equivalent advantages are present for CE by reducing inventory of material and paperwork?

3. Apply TOC to the Engineering Branch.

4. Develop an indepth implementation plan that includes a lesson plan and schedules for the seminars and workshops described in Chapter VI.

Appendix A. Effect-Cause-Effect Diagram



Appendix B: Accumulated Work Order Hour Program

```
Wang VS Integrated Editor - Version  7.02.23         9:39 08/05/91    Page     1
Input File is MWCNSUM  in Library ZMKSRC44 on Volume OL

IDENTIFICATION DIVISION.                                              ZMK10703
PROGRAM-ID. MWCNSUM.                                                  ZMK10805
ENVIRONMENT DIVISION.                                                 ZMK10703
INPUT-OUTPUT SECTION.                                                 ZMK10703
FILE-CONTROL.                                                         ZMK10703
    COPY IVAR  IN I1XXSEL.                                            ZMK10703
    COPY MWOA  IN MWOXSEL.                                            ZMK10703
    COPY MWCN  IN MWOXSEL.                                            ZMK10703
    COPY MIWH  IN MIWPSEL.                                            ZMK10703
    COPY PRT   IN USAFSEL.                                            ZMK10703
    SELECT WORKFILE ASSIGN TO "WORKFILE", "DISK", NODISPLAY,          ZMK10703
        ORGANIZATION IS INDEXED                                       ZMK10703
        RECORD KEY IS WORK-KEY                                        ZMK10703
        ACCESS IS DYNAMIC.                                            ZMK10703
DATA DIVISION.                                                        ZMK10703
FILE SECTION.                                                         ZMK10703
    COPY IVAR  IN I1XXFD.                                             ZMK10703
    COPY MWOA  IN MWOXFD .                                            ZMK10703
    COPY MWCN  IN MWOXFD .                                            ZMK10703
    COPY PRT   IN USAFFD.                                             ZMK10703
    COPY MIWH  IN MIWPFD.                                             ZMK10703
FD  WORKFILE                                                          ZMK10703
       RECORD CONTAINS 0028 COMPRESSED CHARACTERS                     ZMK10711
       LABEL RECORDS ARE STANDARD                                     ZMK10703
       VALUE OF FILENAME IS "WORKFILE"                                ZMK10703
                LIBRARY  IS "#ZBZWORK"                                ZMK10703
                VOLUME   IS IPL-VOLUME                                ZMK10703
                SPACE    IS WORK-SPACE .                              ZMK10703
01  WORK-RECORD.                                                      ZMK10703
    03  WORK-KEY .                                                    ZMK10703
        05  WORK-CTL-INSTL                    PIC  X(04).             ZMK10703
        05  WORK-CTL-CNTR                     PIC  X(01).             ZMK10703
        05  WORK-SHOP                         PIC X(03).              ZMK10703
    03  WORK-HRS                              PIC 9(08)V9.            ZMK10703
    03  WORK-COUNT                            PIC 9(06).              ZMK10703
WORKING-STORAGE SECTION.                                              ZMK10703
01  EXTRACT-INFORMATION.                                              ZMK10703
    03  EXTRACT-IPL-VOL      PIC XX           VALUE "XV".             ZMK10703
    03  IPL-VOLUME           PIC X(06)        VALUE SPACES.           ZMK10703
01  WORK-SPACE               PIC 9(06)        VALUE 128.              ZMK10703
01  DATEIN                   PIC 9(06)        VALUE 0  .              ZMK10703
01  TEMP-IWP                 PIC 9(08)V9      VALUE 0  .              ZMK10703
01  MIWH-FILENAME            PIC X(08)        VALUE "MIWH".           ZMK10703
*-------------------------------------------------------------------- ZMK10703
01  T-LINE1.                                                          ZMK10703
    03  FILLER               PIC X(06)        VALUE "Date:".          ZMK10703
    03  RPT-DATE             PIC 99/99/99.                            ZMK10703
    03  FILLER               PIC X(60)        VALUE                   ZMK10703
        "  Non-completed Work Order Hours by Shop".                   ZMK10703
                                                                      ZMK10703
01  T-LINE2.                                                          ZMK10703
    03  FILLER               PIC X(06)        VALUE "Shop".           ZMK10703
    03  FILLER               PIC X(15)        VALUE                   ZMK10703
        "  Labor Hours  ".                                            ZMK10703
    03  FILLER               PIC X(10)        VALUE                   ZMK10703
        "  # of WOs".                                                 ZMK10703
    03  FILLER               PIC X(18)        VALUE                   ZMK10703
```

```
            "  Direct Hrs".                                                 ZMK10703
                                                                            ZMK10703
       01  D-LINE1.                                                         ZMK10703
           03  FILLER              PIC X(01)        VALUE SPACES.           ZMK10703
           03  D-CTR               PIC X(03).                               ZMK10703
           03  FILLER              PIC X(02)        VALUE SPACES.           ZMK10703
           03  D-LAB               PIC ZZ,ZZZ,ZZ9.9- .                      ZMK10703
           03  FILLER              PIC X(03)        VALUE SPACES.           ZMK10703
           03  D-COUNT             PIC ZZZZZ9 .                             ZMK10703
           03  FILLER              PIC X(03)        VALUE SPACES.           ZMK10703
           03  D-IWP               PIC ZZ,ZZZ,ZZ9.9- .                      ZMK10703
                                                                            ZMK10703
       01  D-LINE2.                                                         ZMK10703
           03  FILLER              PIC X(22)        VALUE                   ZMK10703
               "Work Order file used: ".                                    ZMK10703
           03  WO-FILE             PIC X(08).                               ZMK10703
                                                                            ZMK10703
       01  D-LINE3.                                                         ZMK10703
           03  FILLER              PIC X(22)        VALUE                   ZMK10703
               "Shop file used: ".                                          ZMK10703
           03  SHOP-FILE           PIC X(08).                               ZMK10703
                                                                            ZMK10703
       01  D-LINE4.                                                         ZMK10703
           03  FILLER              PIC X(22)        VALUE                   ZMK10703
               "MIWH Month/Yr:  ".                                          ZMK10703
           03  MONTH-YR            PIC X(04).                               ZMK10703
                                                                            ZMK10703
       PROCEDURE DIVISION.                                                  ZMK10703
       01-START-CODE.                                                       ZMK10703
           COPY IVARREAD IN I1XXCOPY.                                       ZMK10703
           MOVE "MWCN@@@@" TO  IVAR-MWCN-FILENAME.                          ZMK10703
           MOVE "MWOA@@@@" TO  IVAR-WO-FILENAME.                            ZMK10703
           OPEN SHARED MWCN MWOA MIWH.                                      ZMK10711
           OPEN OUTPUT PRT WORKFILE.                                        ZMK10703
           CLOSE WORKFILE.                                                  ZMK10703
           OPEN SHARED WORKFILE.                                            ZMK10703
           MOVE IVAR-MWCN-FILENAME TO SHOP-FILE.                            ZMK10703
           MOVE IVAR-WO-FILENAME   TO WO-FILE.                              ZMK10703
           ACCEPT MIWH-MONTH-YEAR.                                          ZMK10703
           MOVE MIWH-MONTH-YEAR    TO MONTH-YR.                             ZMK10703
           PERFORM 50-START THRU 50-READ-END.                               ZMK10703
           PERFORM 200-PRINT.                                               ZMK10703
           CLOSE MWOA MWCN WORKFILE PRT MIWH.                               ZMK10711
           STOP RUN.                                                        ZMK10703
                                                                            ZMK10703
       50-START.                                                            ZMK10703
           MOVE SPACES TO MWOA-JOB-KEY.                                     ZMK10703
           START MWOA KEY NOT < MWOA-JOB-KEY INVALID KEY                    ZMK10703
              GO TO 50-READ-END.                                            ZMK10703
       50-READ.                                                             ZMK10703
           READ MWOA NEXT AT END                                            ZMK10703
              GO TO 50-READ-END.                                            ZMK10703
           IF (MWOA-WOIND NOT = "A" AND NOT = "W") OR                       ZMK10703
              MWOA-WCM-STAT = "C" OR MWOA-ACTCMDT > 810101                  ZMK10703
              GO TO 50-READ.                                                ZMK10703
           PERFORM 100-START THRU 100-READ-END .                            ZMK10711
           GO TO 50-READ.                                                   ZMK10703
```

```
 50-READ-END. EXIT.                                                    ZMK10703
                                                                       ZMK10703
 100-START.                                                            ZMK10703
     MOVE SPACES TO MWCN-CTL-DATA.                                     ZMK10703
     MOVE MWOA-JOB-KEY TO MWCN-WORK-ORDER.                             ZMK10703
     START MWCN KEY NOT < MWCN-CTL-DATA INVALID KEY                    ZMK10703
        GO TO 100-READ-END.                                            ZMK10703
 100-READ.                                                             ZMK10703
     READ MWCN NEXT AT END                                             ZMK10703
        GO TO 100-READ-END.                                            ZMK10703
     IF MWCN-WORK-ORDER NOT = MWOA-JOB-KEY                             ZMK10703
        GO TO 100-READ-END.                                            ZMK10703
     PERFORM 110-SHOP THRU 110-SHOP-END.                               ZMK10703
     GO TO 100-READ.                                                   ZMK10703
 100-READ-END. EXIT.                                                   ZMK10703
                                                                       ZMK10703
 110-SHOP.                                                             ZMK10703
     MOVE MWCN-SHOP TO WORK-SHOP.                                      ZMK10703
     MOVE MWCN-CTL-INSTL  TO WORK-CTL-INSTL                            ZMK10703
     MOVE MWCN-CTL-CNTR   TO WORK-CTL-CNTR                             ZMK10703
     READ WORKFILE HOLD INVALID KEY                                    ZMK10711
        PERFORM 120-WRITE                                              ZMK10703
        GO TO 110-SHOP-END.                                            ZMK10703
     ADD  1           TO WORK-COUNT.                                   ZMK10703
     IF MWCN-TOT-HRS < MWCN-EST-HRS                                    ZMK10703
        COMPUTE WORK-HRS = WORK-HRS                                    ZMK10703
                      + (MWCN-EST-HRS - MWCN-TOT-HRS).                 ZMK10703
     REWRITE WORK-RECORD.                                              ZMK10703
 110-SHOP-END. EXIT.                                                   ZMK10703
                                                                       ZMK10703
 120-WRITE.                                                            ZMK10703
     MOVE 1           TO WORK-COUNT.                                   ZMK10703
     IF MWCN-TOT-HRS < MWCN-EST-HRS                                    ZMK10703
        COMPUTE WORK-HRS = MWCN-EST-HRS - MWCN-TOT-HRS                 ZMK10703
     ELSE                                                              ZMK10703
        MOVE ZEROES TO WORK-HRS.                                       ZMK10703
     WRITE WORK-RECORD.                                                ZMK10703
                                                                       ZMK10703
 200-PRINT.                                                            ZMK10703
     ACCEPT DATEIN FROM DATE.                                          ZMK10703
     MOVE DATEIN TO RPT-DATE.                                          ZMK10703
     WRITE PRT-RECORD FROM T-LINE1 AFTER ADVANCING PAGE.               ZMK10703
     WRITE PRT-RECORD FROM T-LINE2 AFTER ADVANCING 2.                  ZMK10703
     PERFORM 300-START THRU 300-READ-END.                              ZMK10703
     WRITE PRT-RECORD FROM D-LINE2 AFTER ADVANCING 2.                  ZMK10703
     WRITE PRT-RECORD FROM D-LINE3 AFTER ADVANCING 1.                  ZMK10703
     WRITE PRT-RECORD FROM D-LINE4 AFTER ADVANCING 1.                  ZMK10703
                                                                       ZMK10703
 300-START.                                                            ZMK10703
     MOVE SPACES TO WORK-KEY.                                          ZMK10703
     START WORKFILE KEY NOT < WORK-KEY INVALID KEY                     ZMK10703
        GO TO 300-READ-END.                                            ZMK10703
 300-READ.                                                             ZMK10703
     READ WORKFILE NEXT AT END                                         ZMK10703
        GO TO 300-READ-END.                                            ZMK10703
     MOVE WORK-SHOP TO D-CTR.                                          ZMK10703
     MOVE WORK-HRS  TO D-LAB.                                          ZMK10703
```

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         MOVE WORK-COUNT TO D-COUNT.                                    ZMK10703
         PERFORM 310-READ-MIWH.                                         ZMK10703
         WRITE PRT-RECORD FROM D-LINE1 AFTER ADVANCING 1.               ZMK10703
         GO TO 300-READ.                                                ZMK10703
     300-READ-END. EXIT.                                                ZMK10703
                                                                        ZMK10703
     310-READ-MIWH.                                                     ZMK10703
         MOVE WORK-SHOP        TO MIWH-SHOP .                           ZMK10703
         MOVE WORK-CTL-INSTL   TO MIWH-CTL-INST   .                     ZMK10703
         MOVE WORK-CTL-CNTR    TO MIWH-CTL-CTR    .                     ZMK10703
         READ MIWH INVALID KEY                                          ZMK10703
            MOVE SPACES TO MIWH-CTL-INST.                               ZMK10703
         IF MIWH-CTL-INST NOT = SPACES                                  ZMK10703
            ADD MIWH-LUC-11                                             ZMK10703
                 MIWH-LUC-12                                            ZMK10703
              MIWH-LUC-14                                               ZMK10703
             MIWH-LUC-15                                                ZMK10703
             MIWH-LUC-15-1                                              ZMK10703
              MIWH-LUC-16                                               ZMK10703
             MIWH-LUC-18                                                ZMK10703
             MIWH-LUC-19                                                ZMK10703
             MIWH-LUC-20  GIVING TEMP-IWP                               ZMK10703
         ELSE MOVE ZEROES TO TEMP-IWP.                                  ZMK10703
         MOVE TEMP-IWP TO D-IWP.                                        ZMK10703
```

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Vita

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13. ABSTRACT *(Maximum 200 words)*

The purpose of this thesis is to introduce the Civil Engineering manager to the Theory of Constraints management philosophy and to show how to apply this process of ongoing improvement to the Operations Branch.

One of the reasons for the success of Theory of Constraints in commercial firms is that it provides all levels of management the ability to find simple solutions for bridging the gap between local and global issues. This 'bridge' is built by clearly defining the goal of the organization and using performance measurements capable of predicting the effect of local decisions and actions on the goal.

Using the mission statement from Civil Engineering Doctrine and policy statements from The Civil Engineer, a goal is hypothesized for the daily peacetime efforts of a base level Base Civil Engineering Operations Branch. The goal is stated in such a way as to make measurement towards the goal possible. Performance measurements are postulated using the four services provided to base organizations: operations (utilities), job orders, recurring maintenance of base facilities, and work orders.

This thesis also shows that by managing all shops to their maximum efficiency, the maximum potential output of the organization cannot be realized.

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5. Comments

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